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The Effects of Changes in Population Density on Discharges for the Midwestern United States

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The Effects of Changes in Population Density on Discharges for the Midwestern United States

by

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Abstract:

River baseflow is the river discharge supported predominantly by groundwater, and can be greatly impacted by changes in land. Intuitively, the baseflow of a river would decrease with increased urbanization, as urbanization increases the amount of impervious surfaces, limiting the ability of precipitation to infiltrate into the ground and recharge the local groundwater. However, evidence suggests that the baseflow of rivers in urbanized areas can increase as a result of leaky subsurface water infrastructures that add water to groundwater and replenish baseflow. Another reason for the baseflow increase in urbanized watersheds is that water supply systems are over-pressurized by design to reduce the chances of contamination, contributing extra water to the local system. Cities that have decreased in population over the last century may experience an even greater addition to baseflow as leaky water infrastructures may not be attentively maintained due to the fact that there are less people in the area to supply water to. Given these conflicting urban influences on baseflow, it is important to investigate this relationship further. The goal of this project is to empirically investigate how decreased population in urban areas has impacted baseflow in the Midwestern region of the United States, informally called "The Rust Belt". The project uses USGS gage data from streams within the Rust Belt, specifically from the states of Michigan, New York, Pennsylvania, and Ohio. Stream gage data was selected under the criteria that the data was continuous ($\geq$40 years), unregulated, and a drainage basin of $\leq$400 square miles. Six metrics of annual discharge used are 1) baseflow per unit drainage area (BF, m^3/yr); 2) runoff (RO, m^3/yr); 3) total flow (TF, m^3/yr); 4, 5, & 6) and a ratio of these flows to precipitation over area (BF/P/A; RO/P/A; TF/P/A, unitless). The results determined that there is mainly a

positive relationship between depopulation and baseflow in depopulated cities that lie within the geophysical province of the Central Lowlands.

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A Thesis

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Introduction/Background:

As urban areas develop, the amount of impervious surfaces typically increases, producing a decrease in infiltration rate and an increase in runoff (Figure 1). The increased runoff produces a more "flashy" stream with quickly increasing and decreasing discharges, and intuitively less baseflow. However, it has been suggested that the baseflow in urbanized areas is increasing as a result of leaking water pipes and storm/sanitary sewers (Garcia, 2006). This may also be true for depopulated cities, or areas that have experienced a decrease in population. Fewer people in an area place less demand on water system operations and maintenance. The lack of maintenance on water infrastructure can lead to a significant amount of leakage entering the groundwater system and contribute to a substantial increase in baseflow (Garcia, 2006).

Urban development is recognized by the covering of once rural land by impervious surfaces, such as roof area, paved streets, driveways, sidewalks, and parking lots, due to an increase in population density (Stankowski, 1972). The increased amount of impervious surfaces increases the amount of runoff because water is unable to infiltrate the ground. Intuitively, this would result in a decrease in baseflow. Baseflow is a river's discharge supported predominantly by groundwater while runoff is the flow of water, from precipitation and other natural and non-natural sources, over land. Total flow, is effectively the combination of baseflow and runoff (Figure 2). A steady supply of water running though a system, or baseflow, is important to a city's longevity, as it is difficult to sustain a substantial population without proper resources.

Throughout the last century many cities in the Midwestern United States, within an area known as the Rust Belt, have experienced major decreases in population due mainly to the collapse of industrial jobs in the area (Figure 3). Cities like Detroit, Michigan; Buffalo, New York; Pittsburgh, Pennsylvania; and Cleveland, Ohio have lost many of their automotive, steel, and coal industry jobs (Sugrue, 2007, Monroe Fordham, 2014, Glaeser, 2009). The decrease in jobs has driven a decrease in population over approximately the last quarter to half of a century. Population density is strongly correlated to the amount of impervious surfaces. Stankowski (1972), states that "impervious surfaces are synonyms with human presence". Population density was used to assume urbanization based on the methods of Stankowski (1972). The once densely-populated areas now have a significantly lower population, but the same amount of impervious surfaces and water infrastructure, as the physical form of a city does not naturally shrink (Hollander, 2010).

The cities of interest located in the Midwestern portion of the United States represent two major physiographic provinces, the Central Lowlands and the Appalachian Plateau. The Central Lowlands are located in the interior of the United States and are bounded by the Appalachian Mountains to the east, the Great Plains to the west, and extends south to the Gulf Coastal Plain. They are primarily composed of slightly dipping strata of Paleozoic aged shales and limestones. The Central Lowlands' various plains are comprised mainly of hilly-moraines, outwash, and lake plains in the north, and much of it was glaciated during the Pleistocene Epoch. The Appalachian Plateau is situated on the western side of the Appalachian Mountain range and extends from New York to Alabama. A large portion of the gently northwestern sloping plateau is coalfields formed during the Pennsylvanian Period, and is composed primarily of crystalline sedimentary rocks ("Physiographic Regions") (Figure 4).

Primary porosity and permeability are a material's inherent properties that determine how quickly water flows through it and how easily it is retained. How tightly grains are packed together and how resistant to weathering and erosion a material is affects its ability to become faulted and fractured. These faults are fractures are referred to as secondary characteristics because they are not natural, but they still greatly affect the amount of water that goes though and is retained within the material. The development of secondary structures and thus urban karst, however, occurs at a much faster rate than geologic karst.

The increase in urban infrastructure produces anthropogenic features such as urban karst and urban water. Both of these features can increase urban groundwater recharge and consequently increase baseflow, offsetting the losses due to the decrease in infiltration. Urban karst is similar to natural karst in that it is comprised of large underground openings with highly anisotropic and heterogeneous features. The difference between natural karst and urban karst is how these areas form and at what rate.

Many characteristics make urban karst similar to geologic karst. Utility trenches that support runoff are areas analogous to naturally fractured systems and larger underground openings, excavations, and tunnels are analogous to natural conduits, caves, and channels, both of which increase permeability are highly anisotropic and heterogeneous. Storm drains are analogous to naturally occurring sink-hole-like structures. Rain water, as a result of runoff, can be stored in the shallow underground just as in the epikarst. Recharge can be from both diffuse (precipitation and irrigation return flows) and discrete sources (i.e. leaky pipes) (Garcia, 2006). In both karst systems, primary and secondary porosities and permeabilities control the rate at which runoff becomes baseflow and what these discharges mean in terms of total flow.

However, intentionally over-pressurized pipes and leaky water infrastructures, due to poorly maintained water delivery systems and storm/sanitary sewers add volume to groundwater and subsequently baseflow, offsetting to some degree the loss from urbanization. Roughly 20-30% of water loss from distributions systems is said to be added into the system to leakage (Garcia 2006). Such a substantial amount of water is lost from leaky pipes that water distribution companies account for the lost water, calling it "non-revenue water" (IWA, 2014).

Lopes (2013) analyzed 52 unregulated stream gages in 11 states and found that there are increasing baseflow trends with increasing population density in the Appalachian region, while the Coastal Plain region had mostly decreasing baseflow trends with urbanization. Significant results for the New England province show that while baseflow per unit drainage area is increasing, baseflow is decreasing as a fraction of total flow (Lopes 2013). The major factor of influence argues Lopes (2013), is the effect topography has on the ability of water to infiltrate the ground and thus contribute to baseflow. The topography of the land determines the rate at which run off enters the ground. Lopes (2013) states, that the steeper an area is the more difficult it is for runoff to infiltrate the ground, thus stating that flatter topographic regions experience a greater increase in baseflow due to more runoff entering the ground.

The data collected relates urbanization in terms of population density to different types of discharge in various units. Data analysis was done to determine the relationship between population density and discharge, as well as the statistical significance associated with each type of discharge metrics as well as the trend between population density and the three types of discharge in relation to precipitation/area. The types of discharge include baseflow, runoff, and total flow. Population density was plotted against all six of the baseflow metrics and the confidence associated with each was determined through data analysis. Using census data in conjunction with gage data, a correlation between a decrease in population and baseflow can be determined. This project will determine if there is a correlation between depopulation and baseflow amounts in the Midwest urban areas.

Objective:

The objective of this research was to test to see if a correlation between depopulation and baseflow exists. This was accomplished by the following steps: 1) Determining which cities are depopulating in the Midwestern region of the United States; 2) Identify the United States Geological Survey (USGS) river gages located within the specified Rust Belt study areas that record continuous stream discharge data on baseflow, runoff, and total flow; 3) Compiling and investigating discharge metrics including: baseflow as a ratio of precipitation over area (BF/P/A), runoff as a ratio of precipitation over area (RO/P/A), and total flow as a ratio of precipitation over area (TF/P/A). The normalization of these metrics for precipitation and drainage area is explained in methods.

Methods:

Gage Criteria

This study used United States Geological Survey river gage data from rivers found in areas that have experienced a decrease in population in the Midwestern United States, specifically, MI, NY, PA and OH. Approximately five to 10 gages from each state provided the necessary flow data. Historical stream gage data was collected from the records of the USGS Current Water Data under the criteria that the data is continuous and equal to or greater than 40 years, is not immediately downstream of large dams/impoundments and has a drainage area of less than 400 miles^2. Rivers with these conditions produce discharges that are more likely to be affected by the depopulation of cities because of the limiting number of variables. Each gage was then categorized into groups of physiographic province base on its location. Population density was used to assume urbanization based on the methods of Stankowski (1972). For gages that encompassed multiple watersheds, a weighted average of the population density for each county in the watershed calculated to represent one population density sum per gage.

Discharge Metrics

Annual gage discharge data of baseflow, runoff, and total flow was used to generate ratios to precipitation/area in order to determine how much discharge has increased or decreased over time. The six metrics of annual discharge used are:

1) Baseflow per unit drainage area (BF, m^3/yr)

2) Runoff (RO, m^3/yr)

3) Total flow (TF, m^3/yr)

4) A ratio of baseflow to precipitation over area (BF/P/A, unitless)

5) A ratio of runoff to precipitation over area (RO/P/A, unitless)

6) A ratio of total flow to precipitation over area (TF/P/A, unitless)

The first three metrics are obtained from the Web-based Hydrograph Analysis Tool, WHAT (Lim, et. al 2005). WHAT is a hydrographic recovery website that automatically reports stream flow data from the USGS data server. The Web-based Hydrograph Analysis Tool accounts for stream gage data readings for times as short as a day, to decades of compiled data. WHAT uses the flow data in conjunction with the Eckardt digital filter, designed to separate high frequency signals from low frequency signals in a hydrograph. The purpose of this two-parameter digital filtering technique is to provide consistent, reproducible results (Healy, 2010). The precipitation values from the last three metrics will be obtained from the National Oceanic and Atmospheric Administration's (NOAA) rainfall records.

These final three discharge metrics were then analyzed using the regression tool in the data analysis pack as part of Microsoft Excel. Population density was plotted against each discharge metric to determine if a linear trend existed. The statistical significance of each discharge metric was also determined using the regression tool in the data analysis pack. Discharge metrics with a p-value equal to or less than 0.05 are said to be statistically significant and p-values that are equal to or less than 0.01 are said to be highly confident, and are directly related to population density.

The initial three discharge metrics were used to produce correlations between population density and each of the normalized flows on a linear axis. The logarithms of population density and the discharge metrics, BF/P/A, RO/P/A, and TF/P/A, were also plotted against each other on the log axis. The normalized discharge data takes into account for particularly wet or dry years that the gages being tested may have experienced. Testing the data on a linear axis and a log axis allows for a non-linear relationship to be analyzed. It is important to use baseflow, runoff, and total flow because each one behaves differently as a result of urbanization, and thus depopulation. If the trends associated with baseflow and runoff are being looked at, it is also important to look at the trend for total flow, as total flow is a combination of baseflow and runoff.

The linear regression method was used to test the significance of the variable to the other. It was important to use linear regression to correlate the data so as to limit the amount of variables being used in the study. The focus of the study was to determine if a linear trend exists between population density and baseflow, other methods, such as a non- linear regression or principle component analysis may have proved too complicated in this study. The latter two analyses provide for the possibility of a large error due to the amount of variables being taken into consideration. In this study, the linear regression analysis gave the option for clear dependent results using minimal variables. Various flow studies have also been done using the linear regression analysis to produce succinct and accurate results, such as Muthurkrishman (2006).

Results:

Eleven of the gages were located in the state of Michigan; all of the gages are part of the Central Lowlands geophysical province. Six gages from New York State were used in this study all of which are also included in the Central Lowlands. All four of the Pennsylvania gages used are in the geophysical province of the Appalachian Plateau. Of the six gages studied within Ohio State, two were found within the Appalachian Plateau and the other four were found within the Central Lowlands. All of the gages (21 of them) found within the geophysical province of the Central Lowlands produced a greater amount of statistically significant results than those found within the geophysical province of the Appalachian Plateau, regardless of what state the gage was located in.

Statistical analyses of discharge trends that produced a p-value, or a confidence interval, of 0.05 are said to be statistically significant as this value represents a 95% confidence in the relationship between the independent (x) variable and the dependent (y) variable, or trend. In this study, a p-value of 0.01 is said to be highly statistically significant, as it produces a higher level of confidence in the trend, of 99%. Like the p-value, the significance-f represents a confidence in the results. A small significant-f value tells the probability that the equation does not explain the variation in the dependent variable i.e.) that any correlation between the independent and dependent variables is purely by chance, a small significance-f value is desirable.

Twenty, of the total 26 gages, were found to lie within the physiographic province of the Central Lowlands and six gages were found to lie within the Appalachian Plateaus. None of the gages located in the Appalachian Plateaus show a statistically significant relationship for any of the three normalized discharge metrics, BF/P/A, RO/P/A, TF/P/A, in either linear or logarithmic axes, when tested against population density.

Data analysis of the linear data produced 9 gages with statistical significance when comparing population density against BF/P/A, RO/P/A, and/or TF/P/A (Figure 5). A positive coefficient on the independent variable represents a direct or positive relationship: as the independent variable changes, the dependent variable will change in the same direction. For example, as population density increases, discharge would also increase, and the converse (decreasing population density produces decreasing discharge) would also be true. A negative value represents an inverse relationship, that is, as population changes, flow changes in the opposite direction. The positive values highlighted in blue, on the data summary sheets, represent an increase in discharge or flow(s) in relation to the ratio of flow to $\frac{\text{precipitation}}{\text{area}}$, whether it is baseflow, runoff, total flow, or any combination of the three. Inversely, the values highlighted in red, on the data summary sheets, represent a decrease in discharge or flow(s). Values highlighted in dark green represent a confidence interval of 0.05 and show a statistical significance. Values highlighted in light green represent a high confidence interval of 0.01 and show the desired statistical significance (Table 1).

Nine gages show statistical significance for any or all of the three normalized discharge metrics within the linear data, having a confidence interval equal to or less than 0.01. In comparing population density to the final three discharge metrics (BF/P/A, RO/P/A, and TF/P/A), in the linear data, six show a positive trend and four show a negative trend. The gages that have a high confidence interval in the final three discharge metrics, which are the normalized flows in relation to population density, show the same trend for each discharge metric. For example, when there is a high statistical significance for one discharge metric, for a particular gage, there is a high statistical significance for the other discharge metrics of that gage, each representing the same trend (Table 1).

The linear data produced nine gages that have a high confidence interval when comparing population density against BF/P/A. Five of those gages show an increasing, while four of those gages show a decreasing trend. Only seven gages have a high level of confidence in relation to population density and RO/P/A of the linear data four of which, have an increasing trend and three have a negative trend. The high confidence intervals relating population density and TF/P/A show four resulting in a positive trend and four resulting in a negative trend. A majority of the statistically significant data with a high confidence interval (p-value equal ≤ than 0.01) produced a positive trend or a direct relationship between population density and the normalized discharge metrics of BF/P/A, RO/P/A, and TF/P/A, which resulted in more water or flow for that particular gage. All of the gages showing a high statistical significance, a p-value ≤ 0.01, within the linear data are located in the Central Lowlands (Figure 5 and Tables 1, 2 and 3).

The log data (log population density vs. log of the normalized discharge metrics), in general, had greater statistical significance with more p-values equal to or less than 0.05 and 0.01, making the log data more statistically significant on the whole. Twelve out of 26 gages were found to have high statistical significance when population density was compared logarithmically to the normalized discharge metrics of BF/P/A, RO/P/A, and TF/P/A. All 12 of the statistically significant gages can be found in the Central Lowland physiographic province. Of these 12 gages, 11 showed a high statistical significance when comparing the log of population density against the log of BF/P/A; six of which showed a positive trend and five of which showed a negative trend. Ten gages show a high confidence interval in relation to the log of population density and the log of RO/P/A. Of those ten gages, six have a positive trend or a direct correlation and four have a negative trend or an indirect correlation. The high confidence intervals relating the log of population density and the log of TF/P/A show six with a direct correlation and five with an indirect correlation (Figure 6 and Table 4).

The effect of a city's rise in population and fall in population was also determined separately for each gage, although not all cities experienced depopulation. The logarithmic data proved to be more statistically significant when comparing population density to the normalized discharge metrics. Out of 26 gages, 17 represent counties that experienced a population increase and then a population decrease. For the counties that experienced multiple rises and falls in population the first set of population increase/decrease was analyzed. Eight gages, representing one trend, of a rise then fall in population produced statistically significant results with a high confidence interval (p-value ≤ 0.01). Only two of the gages showed statistical significance in both of the individual trend of population density increase and population density decrease, all of which resulted in a positive trend, or direct relationship for each comparison of the log of population against the log of each of the normalized discharge metrics (Table 4).

Data analyses were also run to correlate population density increases and decreases, individually, to the normalized discharge metrics on the linear and log axis. More statistically significant data was produced when the data analysis was run on the log axis. Nine gages had a 99% confidence when the increase in population density associated with the gage was run against the normalized discharge metrics. Seven out of the nine gages that experienced an increase in population density produced a positive trend when compared against the normalized discharge metrics. Similarly, the linear data and the log data produced six gages that show high confidence when comparing a decrease in population density against the normalized discharge metrics. For both the linear data and the log data showing a decrease in population, two gages produced a negative trend and four produced a positive trend. All of the statistically significant data, in both the individual population density increases and decreases, are associated with gages found within the physiographic province of the Central Lowlands (Tables 5 and 6).

Graphs depicting times series between year vs. discharge vs. population density as and cumulative discharges were generated for each statistically significant linear gage. The time series graphs show the trends of the associated discharges in relation to the active years of the corresponding gage in comparison to population density during the same time (Time Series 1-8). The time series graphs provide a visual representation of the relationship between the discharges of baseflow, runoff, and total flow and population density over the active years of the gage they represent. The cumulative discharges graphs show the volume of the discharges in meters^3 for every active year added in sequential order (Cumulative Discharges 1-8). The cumulative discharges graphs provide a visual representation of a change in trend between discharge(s) and population density by showing a change in the slope of the produced line. When the slope of a line in the cumulative discharges graphs changes, it represents a change in discharge. A decrease in the slope would represent less water entering the system, and inversely, an increase in slope would represent more water entering the system.

Discussion:

The majority of the statistically significant (99% and greater with a small significance-f) trends of the logarithmic data of baseflow with respect to population density, were found to lie within the Central Lowlands physiographic province. The discharge associated with the cities and corresponding gages located within the Central Lowlands are more affected by population changes than the Appalachian Plateau province. This may have something to do with the material it is made of. The Central Lowlands, being primarily comprised of shales and limestones, are more susceptible to urban karstification because these rock types are the geologic materials in which natural karst typically forms. By nature, shales and limestone are less resist to erosion and therefore weather more easily, whereas the materials that make up the Appalachian Plateau are crystalline sedimentary rocks and are not typically associated with areas of karst formation, due to their erosional resistivity. The predominance of the gages located within the Central Lowlands may be attributed to the bedrock of the physiographic province. In general, the discharges associated within cities located with the Central Lowlands geophysical province, are directly associated with changes in population density. If a city, located within the Central Lowlands, experiences an increase in population density, that city will likely see an increase in discharge or baseflow. Similarly, if that city were to experience a decrease in population density, it would also experience a decrease in discharge or baseflow.

It was accepted by hydrogeologists that urban areas experienced a decrease in baseflow (Lerner, 2002), for many intuitive reasons. The reason hydrogeologists were focused on the inverse relationship between population density and discharge was mainly due to the focus on the hydrological shifts from the increase in impervious surfaces of an area, and not the fact that human interactions may interfere with the natural processes of a system. Even after studies began being conducted in the late 1950's-early 1960's, baseflow was still believed to decrease with urbanization (Leopold, 1968). This may be due to the fact that baseflow trends may not have had time to adjust to the changes in population density as water does not infiltrate the surface instantly, and there is a lag in the time that surface water becomes groundwater. And, these assumptions certainly do not take into account the population increase and population decrease that is needed to consider this study. Investigations from more recent studies, like Lerner (2002), show that leaks from water distribution infrastructure are, in fact, a significant source of urban recharge, which has a direct effect on baseflow (Brandes, 2005). Lerner (2002) concluded that 20 to 25 percent of baseflow is a result of leakage, and can significantly offset the losses due to decreased infiltration.

Most hydrogeologists today accept that water supply infrastructures, directly associated with urbanization due to an increase in population density, generate a large amount recharge through leakages, which directly affects baseflow (Lerner, 2002). The recharge associated with urban infrastructures is produced mainly by secondary porosity and permeability, such as tunnels, buried utilities, garages, and other buried structures, as well as the faults and fractures that result from these structures, which disturb the natural structure of the ground (Garcia 2006). According to Lerner (2002) roughly 50% of the impervious cover should be treated as permeable due to the porosity and permeability of secondary characteristics (Garcia, 2006). Secondary characteristics may develop at a faster rate in the Central Lowlands as compared to the Appalachian Plateau because of the differences in regional climate. The Central Lowlands geophysical province experiences a slightly harsher annual climate than the Appalachian Plateau. Typically, the winter months experience colder temperatures for a longer duration in the Central Lowlands (Antipova, 1979). The continual freezing and thawing cycles inherent of the regional cities located within the Central Lowlands, expedites the creation of secondary porosity and permeability structures, like fractures and faults, increasing the ability of urban water systems to recharge local groundwater supplies.

Eight of 12 statistically significant gages associated with cities located within the Central Lowlands geophysical province had a positive correlation between population density and discharge. These trends are solidified by their p-values ≤ 0.01 and there equally small significance-f values. When there are more people in an urban area baseflow increases and conversely, when there are less people in an urban area baseflow decreases. When a densely populated city with a substantial amount of impervious surfaces, experiences an increase in discharge and baseflow, it can be mainly attributed to the leaky water infrastructure. The leaky water infrastructure contributes enough water into the system to not only make up for the lack of runoff infiltrating the system, due to an increase in imperviousness, but enough excess to ultimately increase the baseflow.

The gages that represent a direct correlation, or a positive trend, between discharges and population density suggest that, although base flow and runoff are both increasing, the increase in baseflow has more of an effect on the contribution to total flow. This means that the urban karstification has a greater influence on the system than the imperviousness. And the gages that have an indirect correlation, or a negative trend, between discharges and population density, are the result of the imperviousness having a greater effect on the system than the karstification.

Some of the results are counterintuitive, in that, gages that produced a negative trend in baseflow also produced a negative trend in runoff. It would seem that if baseflow were decreasing as a result of increased imperviousness, runoff would increase as a result of the increase in imperviousness. However, the gages that show a negative trend suggest otherwise (Table 1 and 2).

The subsurface water infrastructure associated with urban areas acts as a conduit for flow in the same way caverns and tunnels in natural karst systems act. Like many things, urban water infrastructures leak. Some leaks are by design due to over-pressurization, to decrease the chance of contamination. If water is leaking out, it makes it less likely for pollutants to seep in and contaminate the clean water supply and this leakage is found to be acceptable up to a point. Water supply companies account for this loss of water and even factor it into their cost budget as "non-revenue" water (IWA, 2014).

During the last turn of the century, the cities situated in the Midwestern portion of the United States were centers of commerce with booming industry, millions of people, and state of the art water infrastructures to support them all. Those cities have since whittled away to mere hundreds of thousands, and more importantly so has their supporting water infrastructures. The average lifespan of cast iron drain lines, much like those that would have been installed in these industrial centers, is approximately 75-100 years (Bousquin, 2010). Now that the lifespan of these water infrastructures is approaching, it is more important than ever to understand their erosive capabilities due to over-pressurization and leaks, since they are being compounded by system failure.

The reason the depopulated cities of the Rust Belt, situated within the Central Lowlands physiographic province, experience the urban karstification processes more intensely than other urban areas is because of the material of the underlying rock. The leaky water infrastructure has a much greater effect on the shales and limestone of the Central Lowlands because shales and limestones are much less resistant to weathering and erosion when compared to the crystalline rocks of the Appalachian Plateau. The urban karstification process happens at a faster rate than it would naturally because the over-pressurization of the subsurface water infrastructure erodes the surrounding rock more quickly than naturally flowing waters in typical karst systems.

It is important, based on this study and other studies (e.g., Lopes 2013), to note that different regions experience changes in discharge characteristics differently as population varies. This study would be most beneficial to cities experiencing a change in population density located within the Central Lowlands. Most of this study's statistically significant results were located in this province, and cities in states such as Ohio, Michigan, and Indiana could use this to prepare for future scenarios. The relationship between depopulation and baseflow can be used to better understand how humans alter the natural environment even after they have. This research can also give insight to what can potentially be done to remediate this effect. The urban karstification process is one that is extremely difficult and expensive to prevent and reverse. Urban karstic areas can be filled in with various rebuilding materials, but these too will eventually erode too due to the over-pressurized and leaky subsurface water infrastructures. Whether a city located within the Central Lowlands begins to experience an increase in population density or a further decline in population density the resulting trend associated with baseflow will happen at a much faster rate now that the karstic structures exist

Results from other studies comparing urbanization to baseflow show that an increase in baseflow after urbanization is more likely to occur than a decrease in baseflow. Hydrogeologists (Tenant, 1975 and Hammer 1973) in the past have concluded that increased imperviousness reduces infiltration and therefore baseflow, but that the municipal water imported into the drainage area was offsetting, somewhat, the effects of reduced infiltration.

These results are consistent with the work of Klein (1979), who also found a definite positive relationship exists between imperviousness and baseflow. Klein (1979) concluded that the positive response of baseflow is dependent upon the particular physiographic province a stream, or in this instance a gage, is located within. This correlation is attributed to the porosity and permeability of the bedrock in the geophysical province.

If a statistically strong positive correlation exists between population density and baseflow, the two parameters are directly correlated. Furthermore, with the decreased infiltration countered by the increase leakage, causes for this correlation can be explained. The positive correlation means that as population density increases so does baseflow, and inversely, as population density decreases, baseflow decreases. Establishing this trend can help cities facing similar declines in population prepare for a change in baseflow and better manage potential future implications. Water conservation measures may be implemented in places forecasted to have declining discharge, while flood mitigation efforts might be installed in locations with future increases.

The majority of the statistically significant data (eight out of 12 gages) produces a positive correlation between population density and baseflow. When population density increases, discharge increases and when population density decreases, flow decreases. The less people in an area, the lesser the amount of supplied water, thus the fewer the amount of leaky pipes. However, the urban karstification process has already taken place and would be incredibly expensive and time consuming to remediate. If these Midwestern cities that have experienced a decrease in population within the last quarter to half a century start to repopulate, changes in baseflow driven by changes in population, will happen much faster due to the karst systems that have been created. Time series and cumulative discharge graphs were created for the eight gages with statistically significant linear trends (Figures 7 & 8). Descriptions and interpretations of the trends of individual gages are included in these figures.

Some of the cities associated with gages that were analyzed have not experienced a decrease in population density but may experience a population loss in the future, like some of their regional neighbors. The gages that have not yet experienced a cities' decrease in population density may produce some more statistically significant data in the years to come, provided that those cities experience depopulation.

However, the effect of population density on baseflow and discharge has not been extensively investigated for the cities within the Rust Belt. A significant amount of data was analyzed with the goal of determining if a correlation exists between baseflow to changes in population density. Not only was a positive trend produced for a majority of the data, but all of the statistically significant data was associated with gages, and subsequently cities, all located with the Central Lowlands physiographic province due to the province's unique inherent compositional characteristics in conjunction with the time frame in which it was initially urbanized.

Future studies may include how the baseflow of cities located in other physiographic provinces respond to changes in population density, as a result of the provinces' composition. Studies may also include any environmental impacts associated with a rapid increase or decrease in baseflow as a result of population density fluctuations. Important findings may result from looking at the economic implications associated with not only the increases and decreases of baseflow and population density, but in the cost of which it takes to remediate such urban karstic structures or leaky water infrastructures that are not intentionally over-pressurized. Regardless of what is done with this data in terms of manipulation or interpretation, it is important that it be continually recorded so as to be aware of any resulting changed in baseflow, as a result of population density change, soon after it is occurring.

Bibliography:

"A Chronology of Bethlehem Steel." *The Steel Plant Museum of Western New York.* Monroe Fordham Regional History Center at Buffalo State College, n.d. Web. 13 Jan. 2014.

Antipova, A. V. "Central Lowland." *The Great Soviet Encyclopedia*. 3rd ed. N.p.: Gale Group, 2010. *The Free Dictionary*. Web. 24 Apr. 2014.

Arnold, C.L. Jr., & Gibbons, C.J., 1996. Impervious surface coverage: The emergence of a key environmental indicatory: Journal of the American Planning Association, v. 62, p.243.

Brandes, David, Gregory J. Cavallo, and Michael L. Nilson. "Base Flow Trend in Urbanizing Watersheds of The Delaware River Basin." *Journal of the American Water Resources Association* (2005): 1377-391. *American Water Resource Association*. Web. 13 Apr. 2014.

Bousquin, Joe. "Types of Plumbing Pipes and Their Lifespans." *Houselogic.* N.p., 12 Nov 2010. Web. 04 May 2014.

The Free Dictionary. Farlex, n.d. Web. 13 Apr. 2014.

Garcia-Fresca, B., 2006. Urban-enhanced groundwater recharge: review and case study of Austin, Texas, USA. Urban Groundwater, Meeting the Challenge. International Association of Hydrogeologists Selected Papers; p.3-18.

Glaeser, Edward L. "Revenge of the Rust Belt." *Economix Revenge of the Rust Belt Comments*. The New York Times, 9 Feb. 2009. Web. 13 Jan. 2014.

Graham, P.H., Costello, L.S., & Mallon, H.J., 1974. Estimation of Imperviousness and Specific Curb Length for Forecasting Stormwater Quality and Quantity, Journal Water Pollution Control Federation, 46(4):717-725.

Hammer, T. R., 1973. Effects of Urbanization on Stream Channels and Stream Flow. Regional

Healy, R.W., 2010. Estimating Groundwater Recharge. Physical Streamflow Hydrograph Analysis, p. 87.

Hicks, R.W.B. & Woods, S.D., 2000. Pollutant Load, Population Growth and Land Use. Progress: Water Environment Research Foundation. 11: Page 10

Klein, Richard D. "Urbanization And Stream Quality Impairment." *Journal of the American Water Resources Association* 15.4 (1979): 948-63. Print.

Lerner, D.M., 2001. Identifying and Quantifying Urban Recharge: A Review. Hydrogeology Journal 10:143-152.

Leopold, L.B., 1968. Hydrology for Urban Planning- A Guidebook on the Hydrologic Effects of Urban Land Use. U.S. Geological Survey Circular 554, Washington, D.C.

Lim, K. J., Engel, B.A., Tang, Z., Choi, J., Kim, K., Muthukrishnan, S., & Tripathy, D. 2005 Automatics Web GIS Based Hydrograph Analysis Tool, WHAT: JAWRA, Dec v. 41, p. 1407-1416

Lopes, J.M., 2013. A Historical Empirical Analysis of the Relationship between Urbanization and Stream Baseflow in the Eastern United States.

Meyer, S.C., 2002. Investigation of Impacts of Urbanization on Base Flow and Recharge Rates, Northeastern Illinois: Summary of Year 2 Activities. Proceedings of the Annual Illinois Ground Water Consortium Conference, Illinois Groundwater Consortium, Carbondale, Illinois. April 2014.

Muthurkrishman, Suresh, Jon Harbor, Kyoung Jae, Lim, and Bernard A. Engel. "Calibration of a Simple Rainfall-runoff Model for Long-term Hydrological Impact Evaluation." *Urban and Regional Information Systems Association* 18.2 (2006): 35-42. Web. 4 May 2014.

"Non-Revenue Water." *IWA* -. International Water Association, 2014. Web. 13 Apr. 2014.

"Physiographic Regions." *United State Geological Survey*. United States Department of the Interior, 27 Mar. 2002. Web. 22 Apr. 2014.

Science Research Inst ., Philadelphia, Pennsylvania, 270 pp.

Stankowski, S.J., 1972. Populations Density as an Indirect Indicator of Urban and Suburban land-Surface Modification, U.S. Geological Survey, Professional Paper: Report 800B, B219-B224.

Sugrue, Thomas J. "Motor City: The Story of Detroit." *The Gilder Lehrman Institute of American History*. The Gilder Lehrman Institute of American History, 2007. Web. 13 Jan. 2014.

Tennant, Donald Leroy. "Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources." *Fisheries* 1.4 (1976): 6-10. Print.

Figures:

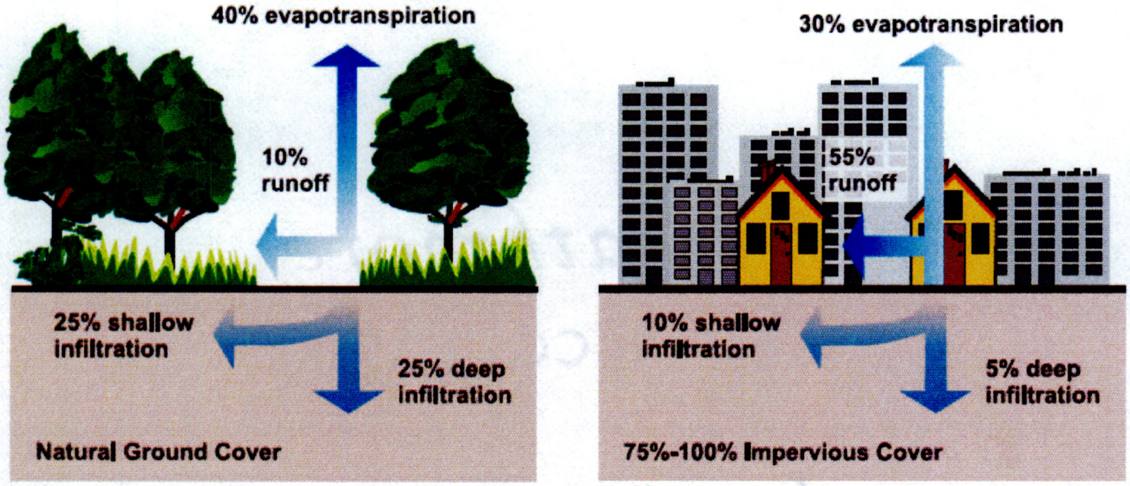

Figure 1. A figure showing the effects of urbanization on a once rural area and what that means in terms of runoff and infiltration rates. The urban area shows an increase in runoff and a decrease in infiltration, as a result of an increase in imperviousness, in comparison to the rural land.

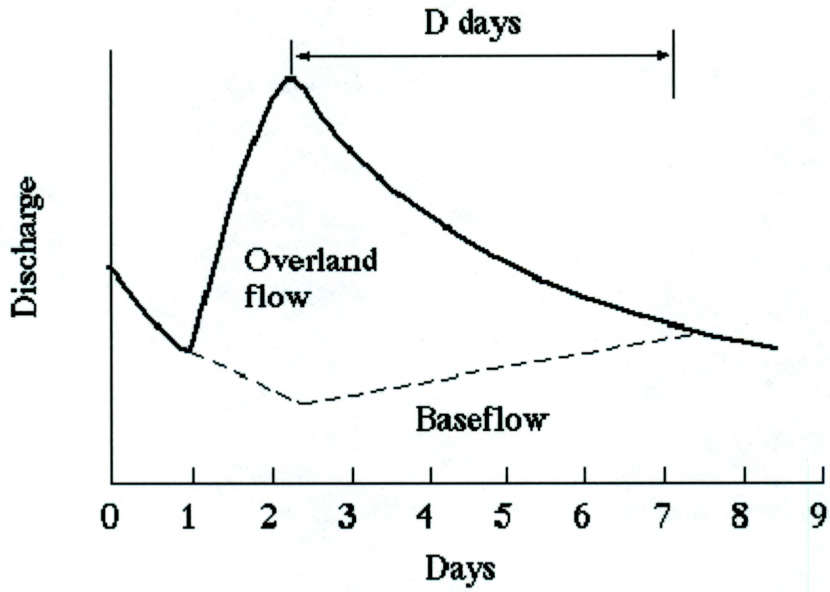

Figure 2. A simple hydrograph representing baseflow, runoff, and total flow. Baseflow is denoted by the dashed line across the bottom of the hydrograph, runoff (overland flow) is shown by the steep increaing peak, and total flow is the combination of baseflow and runoff, which is represented by anythign undering the solid black line of the hydrgraph. The steeper the increasing trend of the overland flow, the more "flashy" the stream.

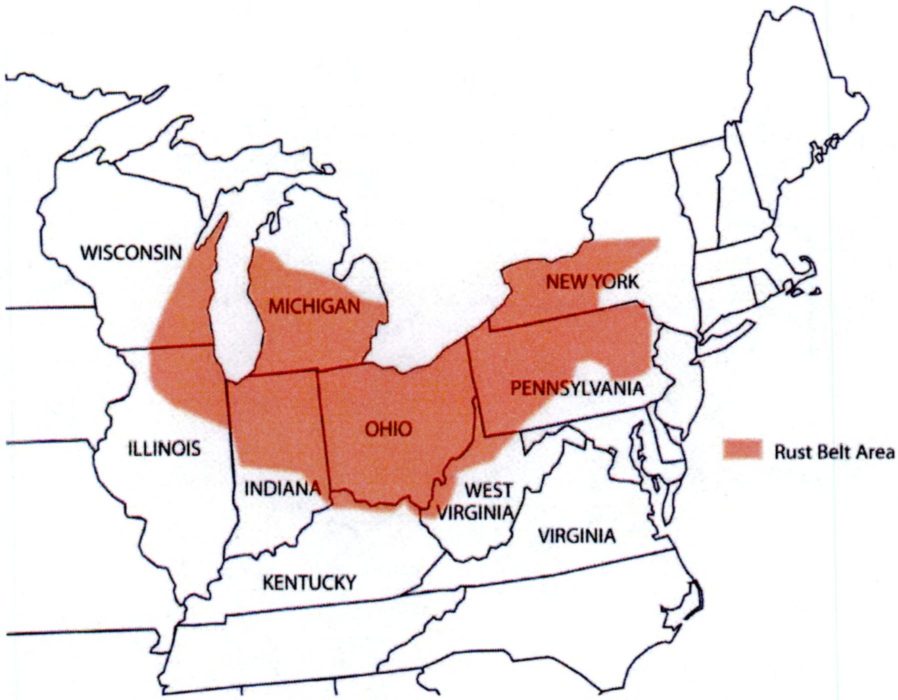

Figure 3. A geographic depiction of the area of interest, the Midwestern portion of the United States, nicknamked "The Rust Belt". Cities of interest included in this area are Detroit, Michigan; Buffalo, New York; Pittsburgh, Pennsylvania; and Cleveland, Ohio.

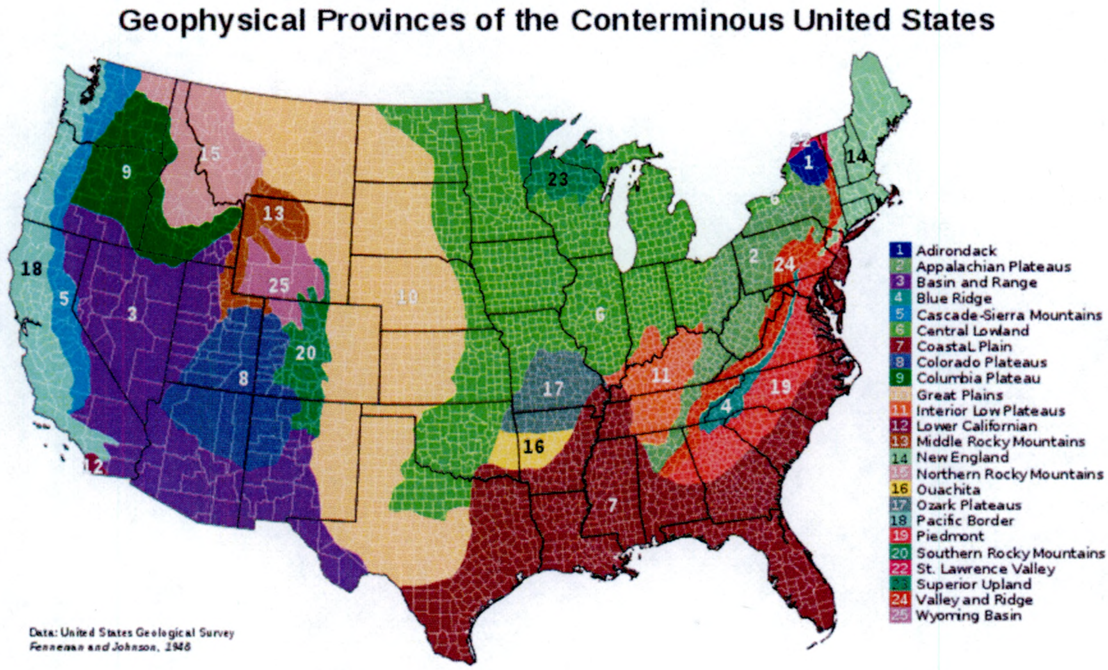

Figure 4. A geological representation of the area of interest in the Midwestern portion of the United States. The olive green color, or geophysical province #2, shows the Appalachian Plateaus, which are primarily comprised of crystalline sedimentary rocks. The light green color, or geophysical province #6, show the Central Lowlands, which are mainly composed of shale and limestone.

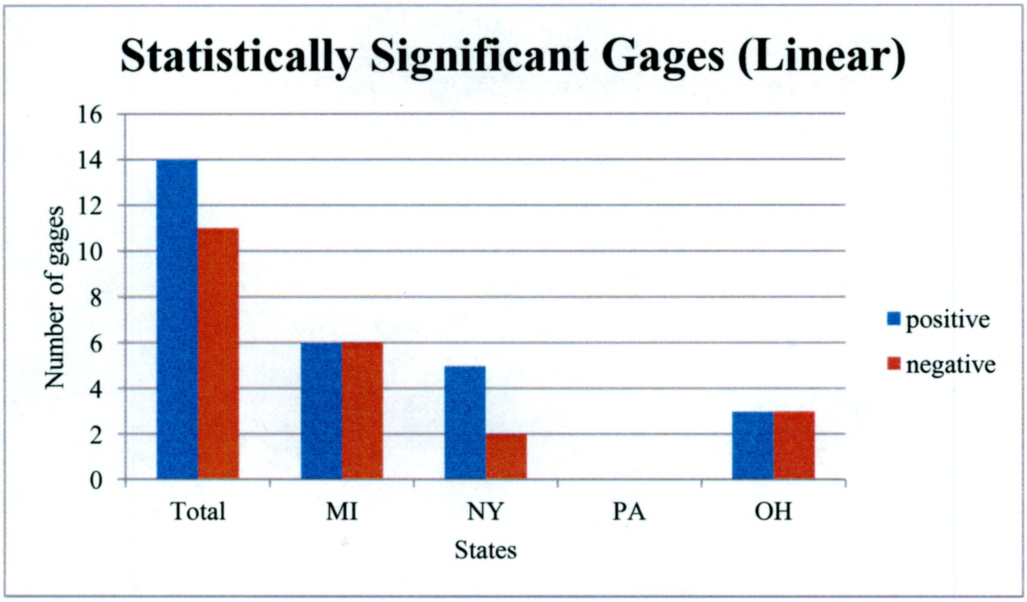

Figure 5. A representation of the cumulative amount of statistically significant linear gage data, showing both positive and negative trends, per state. A majority of the statistically significant gages produced a positive trend.

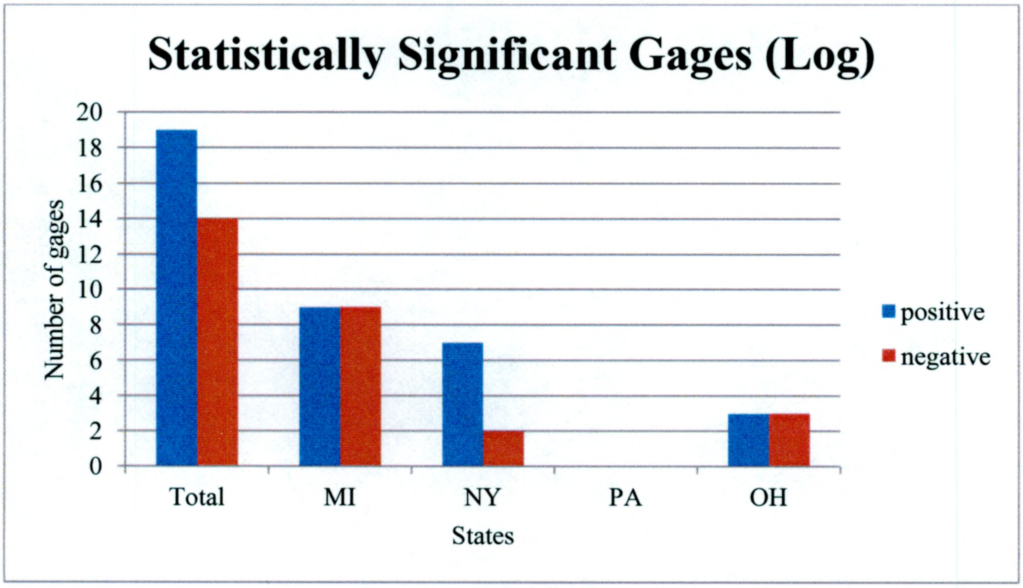

Figure 6. A representation of the cumulative amount of statistically significant logarithm gage data, showing both positive and negative trends, per state. A majority of the statistically significant gages produced a positive trend.

Figure 7. The following images represent times series between years vs. discharge and years vs. population density for each gage that produced statistically significant data for all three of the discharge metrics (BF, RO, and TF) in the linear regression. The times series graphs show the amount of water in meters^3 for each of the discharge metrics, plotted against time, in years, of the active gage, and the population density of the county. Baseflow is represented by the blue diamonds, runoff by the red squares, total flow by the green triangles, and population density by the purple x's.

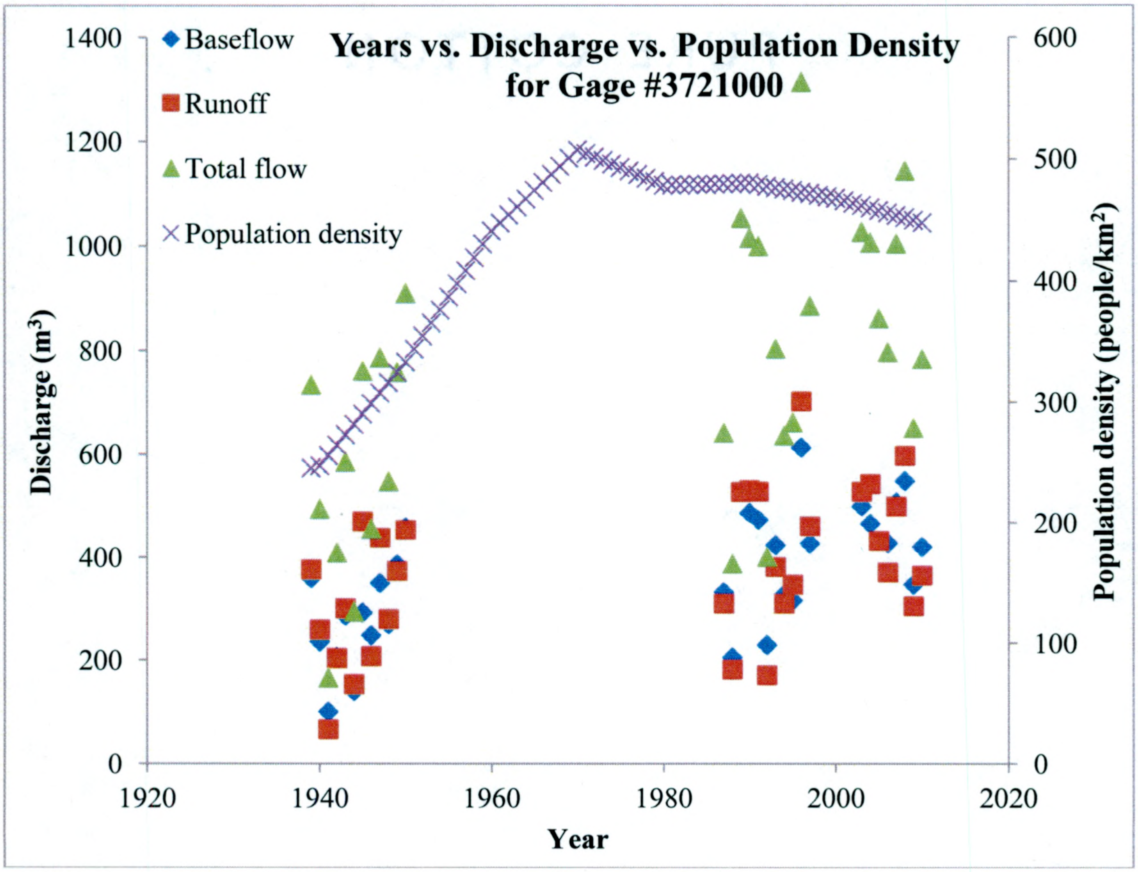

Figure 7. Times Series 1. The gage for Wolf Creek at Dayton, Ohio is missing approximately 20 years of stream flow data, denoted by the empty space in the center of the graph. It is difficult to interpret a trend between population density and discharge with the absence of so much gage data in the middle of the time of interest, but the data appears to slope downward with the decreasing population density, which is consistent with the positive relationship produced by the data analysis.

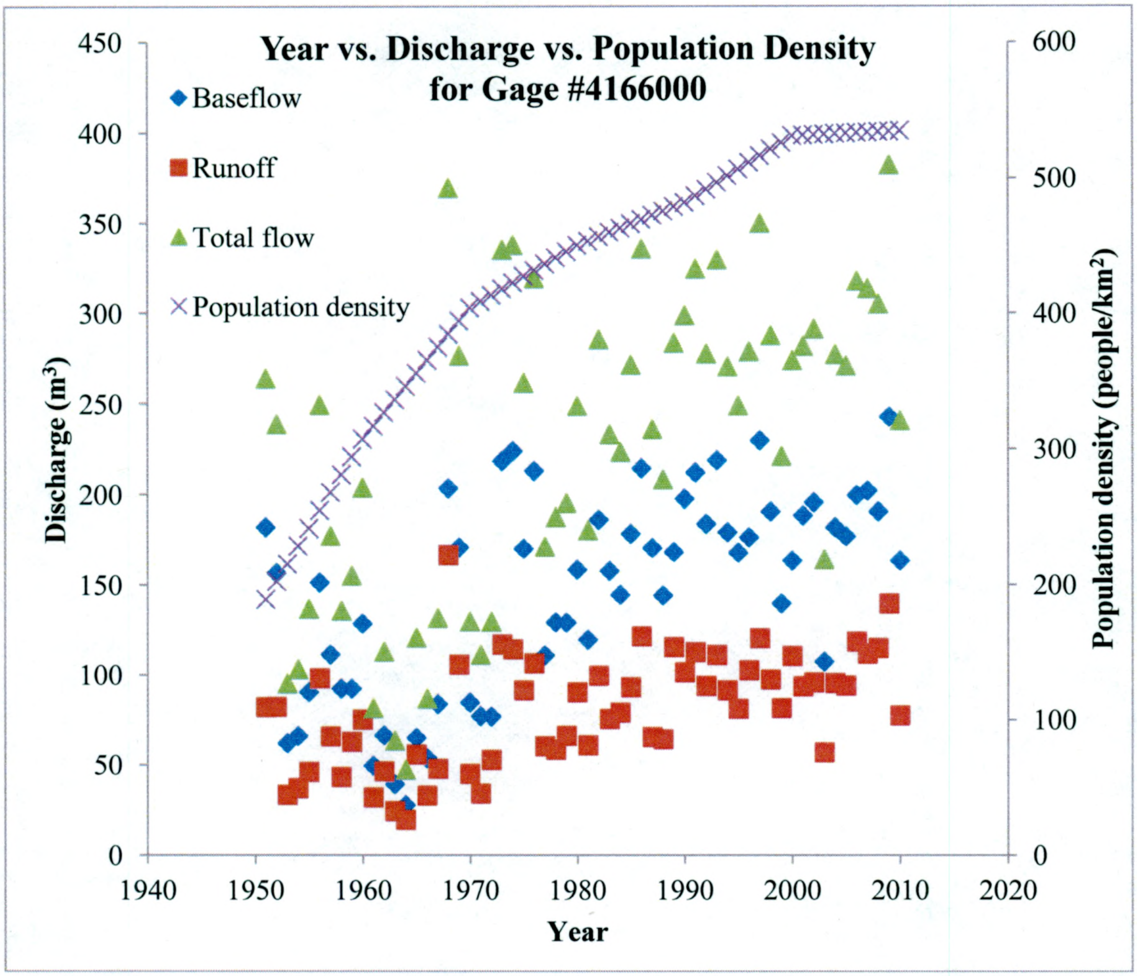

Figure 7. Time Series 2. The gage for River Rouge in Michigan shows a steady increase in population over the last half century, leveling out near the new millennium. All of the discharges associated with the gage increase along with population density. This could be a direct result of the area's urbanization. As urbanization increase so does imperviousness as results in an increase of runoff. Baseflow is also increasing as a result of the leaky water infrastructure associated with the city. The combination of the increasing runoff and baseflow produces an increase in the total flow associated with the gage. The trends of the increases occur at relatively the same time interval.

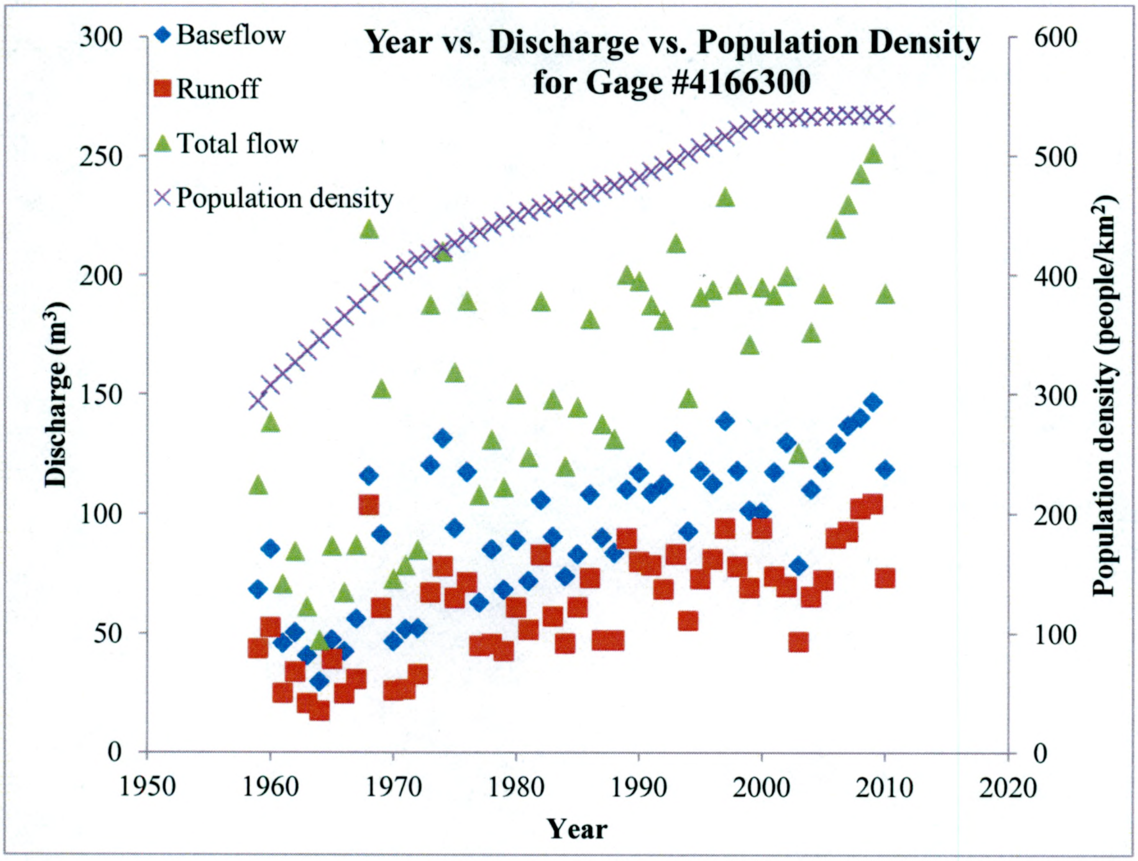

Figure 7. Time Series 3. The population density for Oakland county, associated with Upper River Rouge in Michigan experienced a steady increase in population density over approximately the last half century, leveling off around the new millennium, much like the gage before it. Interestingly, when the population density levels off around the year 2000, the discharges are shown to increase. This may be due to population density reaching its peak, and therefore urbanization reaching its peak. A peak in population and urbanization would result in an increase in baseflow, because water supply system would be delivering more water to more people and thus leaking more. A peak would also result in an increase in runoff as a result of all the imperviousness. Increased baseflow and increase runoff results in increased total flow. Note that the increases in discharge, caused by the leveling off of population density, occur roughly 10 years after the initial leveling off.

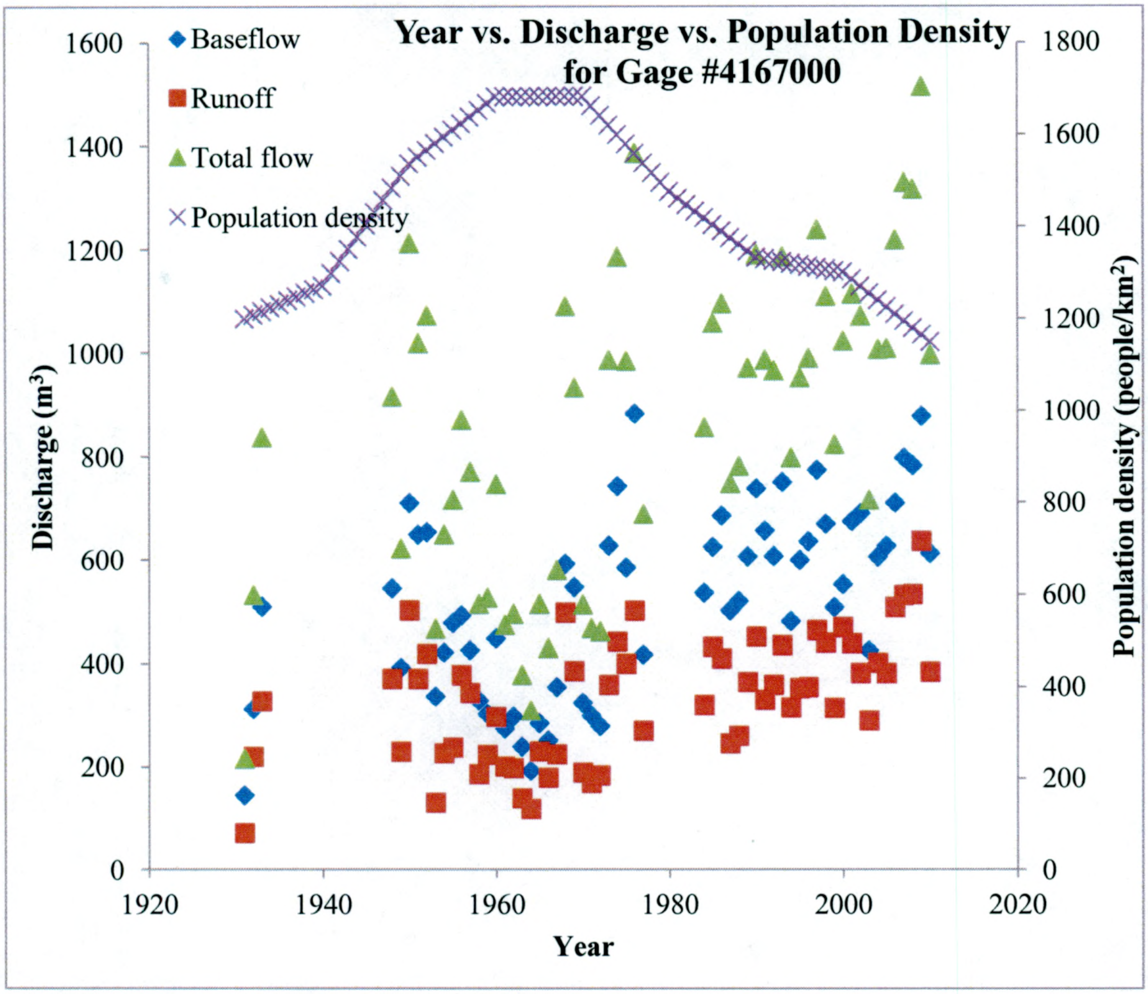

Figure 7. Time Series 4. Middle River Rouge in Wayne County, Michigan shows a decrease in population density around 1970, after a consistent increase followed by a leveling off in the earlier part of the century. The decrease in population is accompanied by an increase in baseflow, runoff, and total flow. This is one of the few gages that show an indirect relationship between population density and discharge.

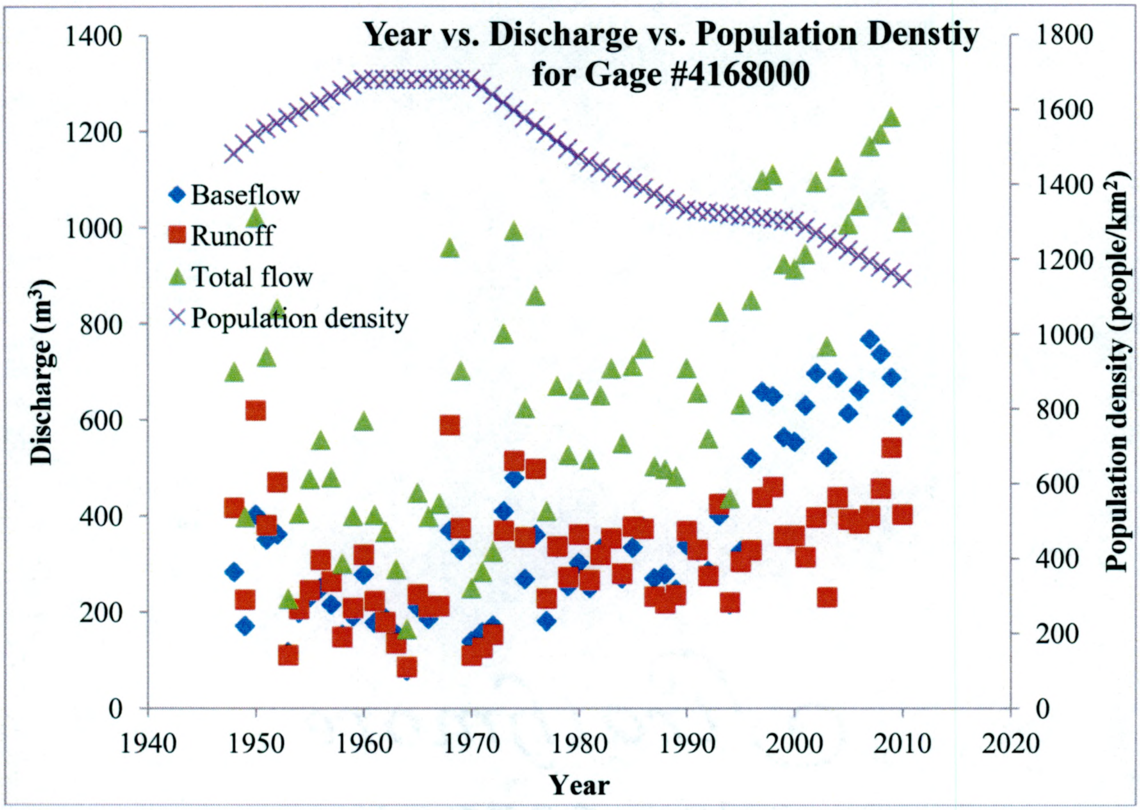

Figure 7. Time Series 5. The Lower River Rouge gage in Wayne, Michigan also shows an indirect correlation between population density and discharge. The increases in discharges occur when population density starts to decrease, around the year 1990.

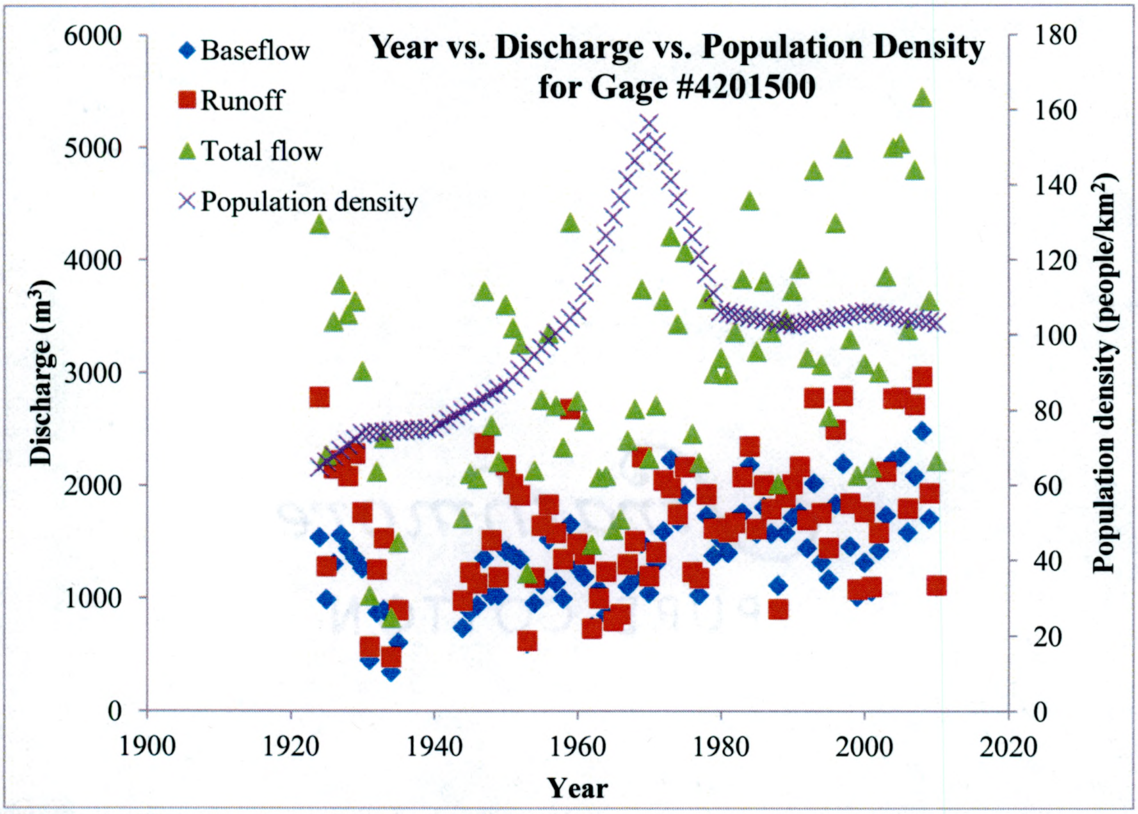

Figure 7. Time Series 6. For the Rocky Rive gage in Ohio, discharges increase when population density decreases, showing an indirect correlation, consistent with the results of the linear regression.

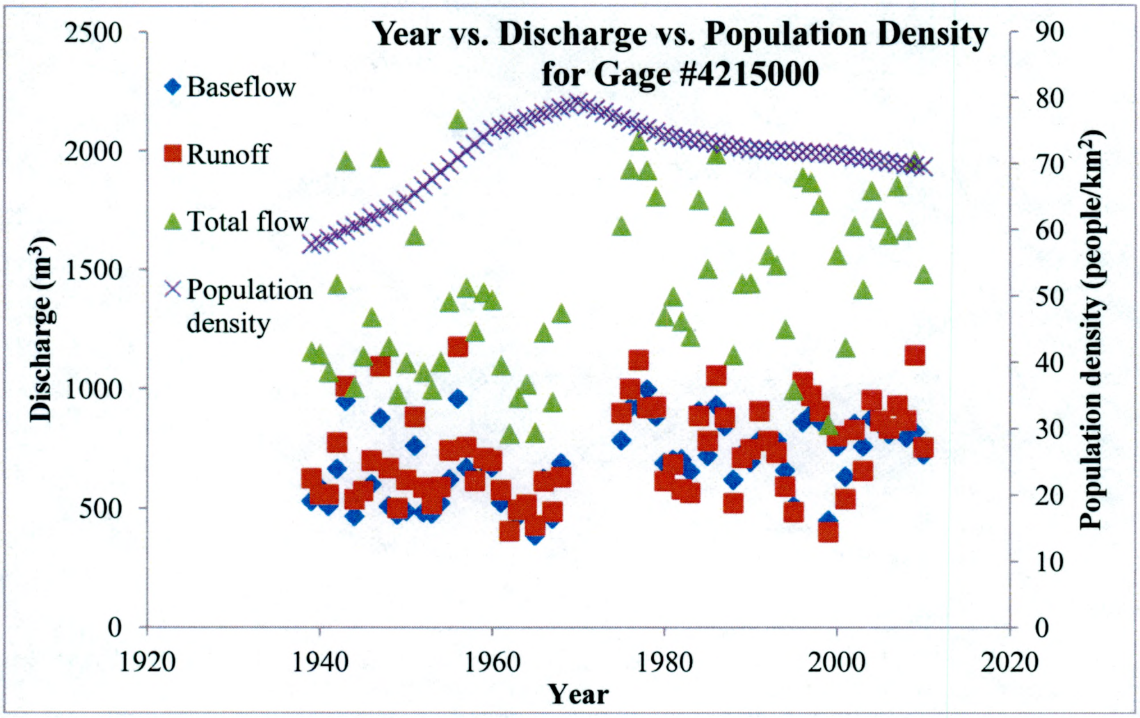

Figure 7. Time Series 7. The gage for Cayuga Creek in New York shows a direct correlation between population density and discharges, in that as population density decreases, towards the end of the century, discharges also decrease, despite a brief gap in gage data.

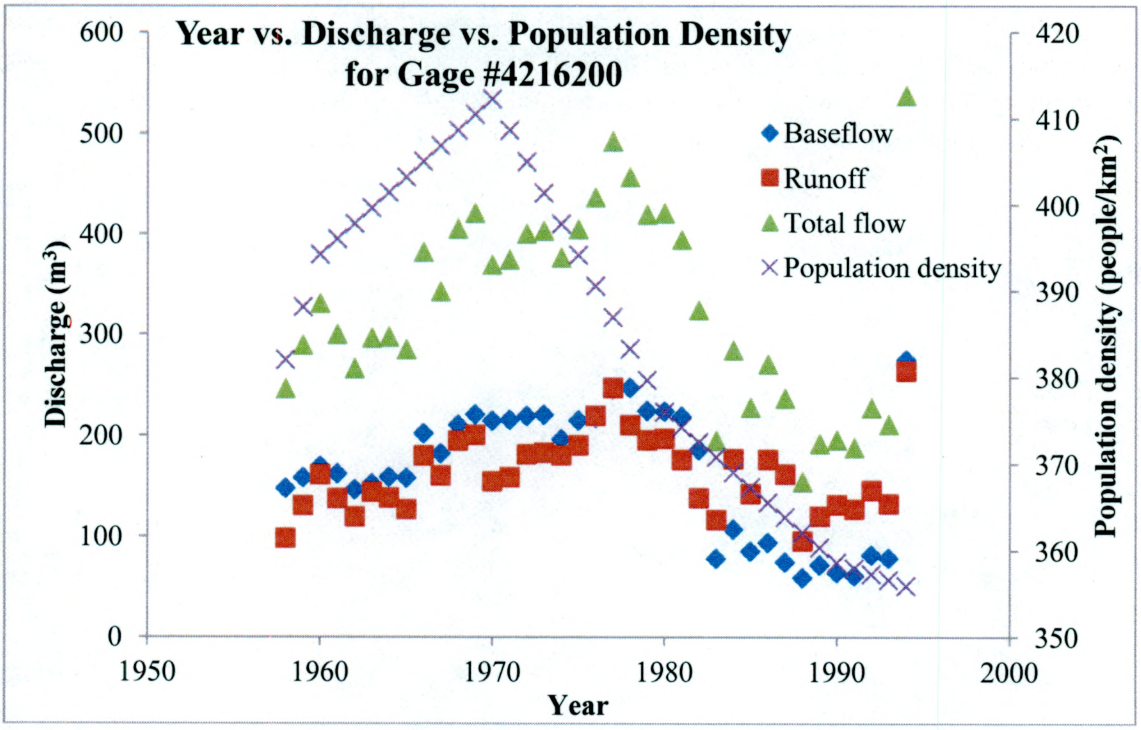

Figure 7. Time Series 8. The Scajaquada Creek gage in New York shows a steadily dramatic population decrease since 1970 coupled with a decrease in discharges but with an interesting lag. A reason for the lag in decreasing discharges in relation to population density may be a result of the water infrastructure "catching up" to the changes in population density.

Figure 8. The cumulative discharge graphs show an annual increase of the measured gage discharges by comparing each sequential year to the amount of discharge for that year added to the year prior; the same legend colors representing discharges apply. A change in the slope of the cumulative discharges represents a change in annual discharge. An increase in cumulative discharge slope would represent more water entering the system while a decrease in slope would represent a decrease in water. A gap in the data is indicative of a gap in gage readings; some gages had incomplete records.

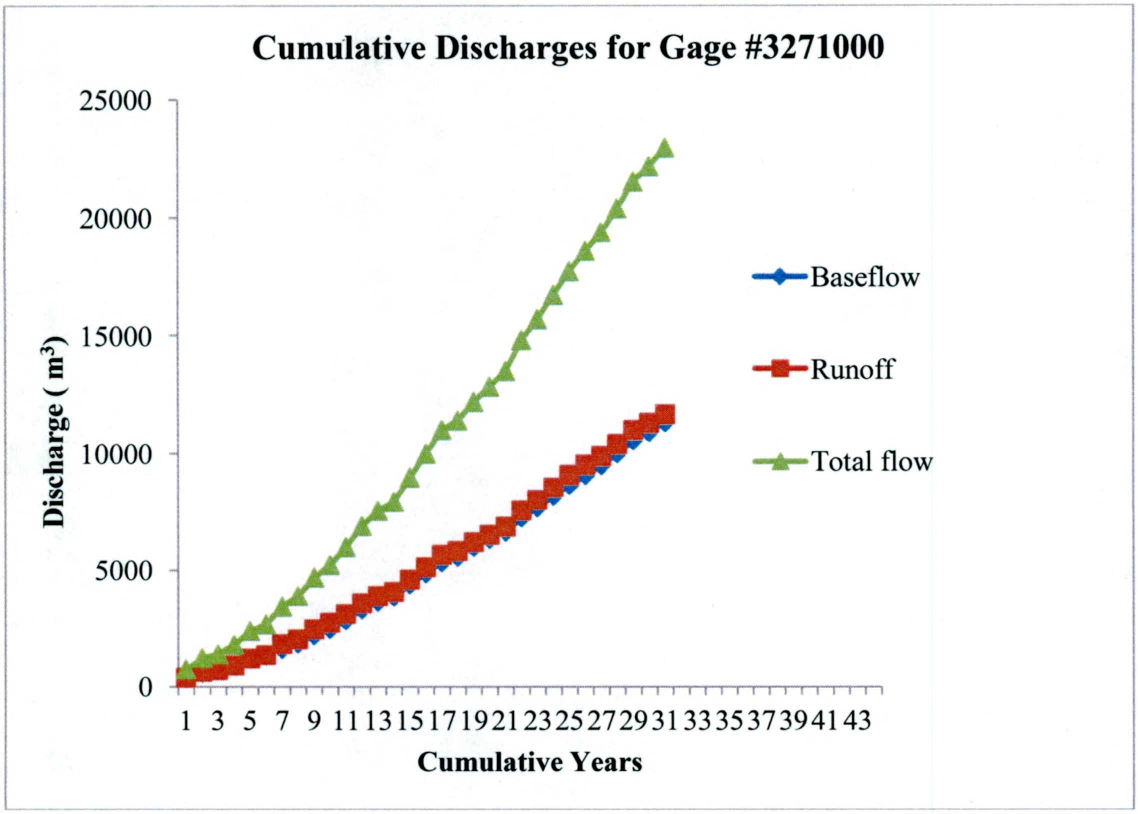

Figure 8. Cumulative Discharge 1. An increase in discharge is represented by the steeply increasing slope, associated for Wolf Creek at Dayton, OH, and correlate to the positive trend produced from the linear regression, resulting in more discharge with an increase in population.

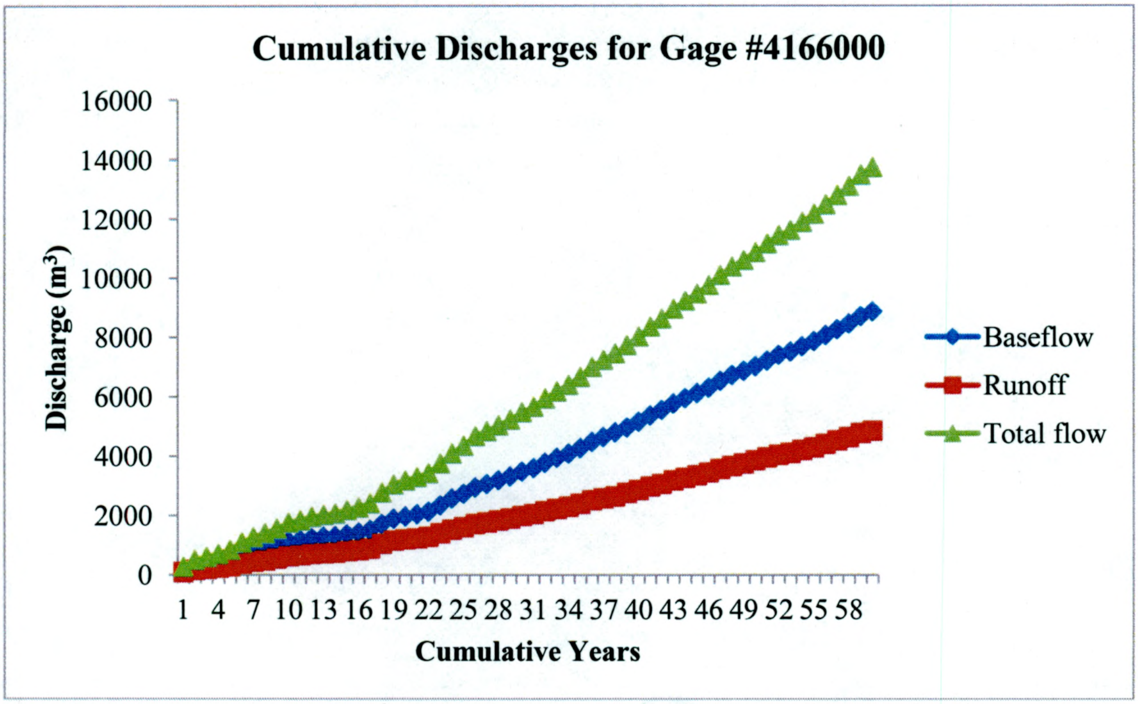

Figure 8. Cumulative Discharge 2. An increasing slope is consistent with the positive trend produced in the linear regression for the River Rouge in Michigan and represents an increase in discharge as population density increases.

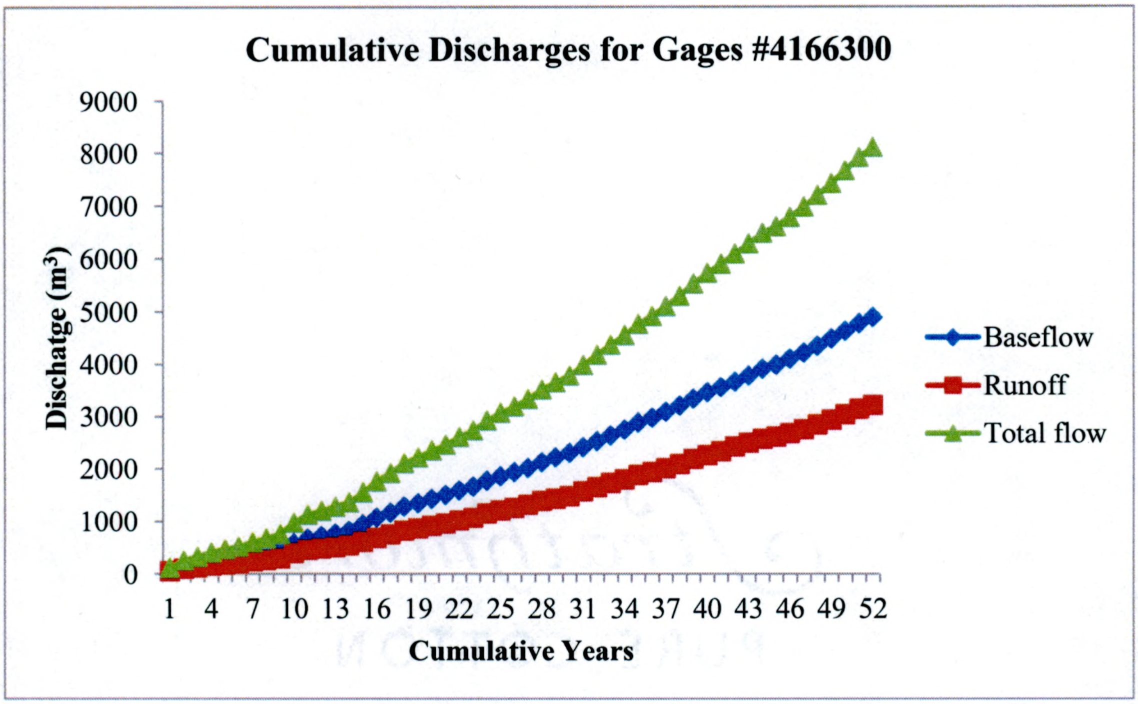

Figure 8. Cumulative Discharge 3. The cumulative discharge data for the Upper River Rouge in Michigan shows a steep increase in discharges over each additional year, consistent with its positive trend produced by linear regression.

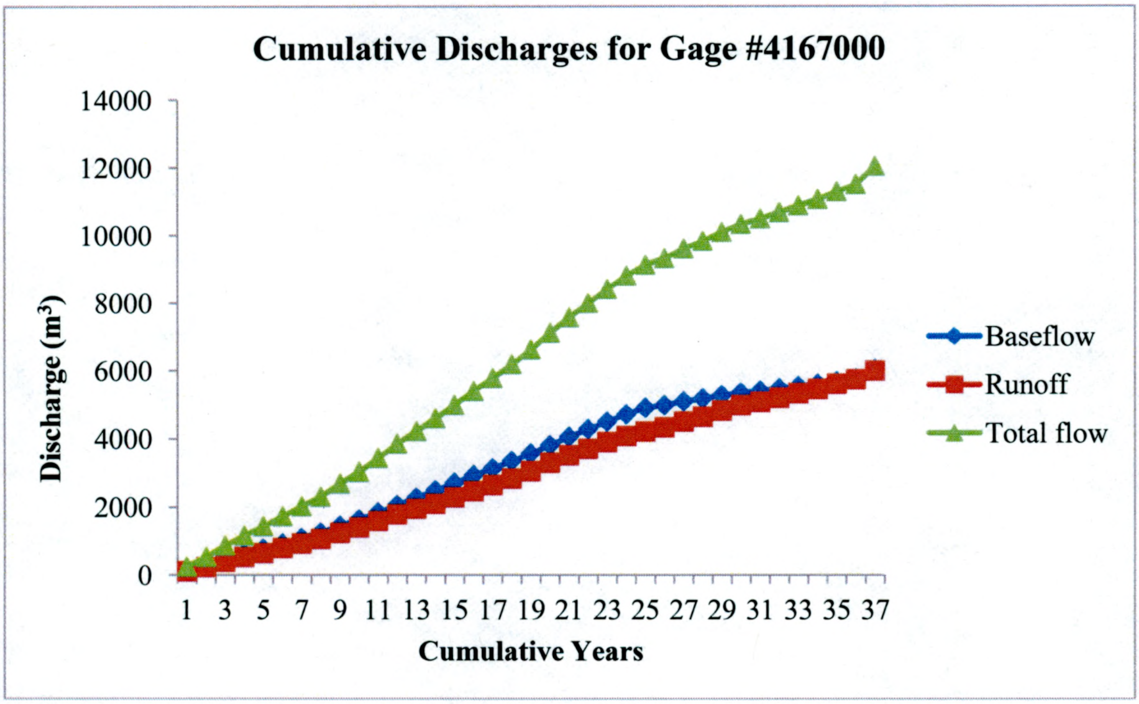

Figure 8. Cumulative Discharge 4. An abrupt change in slope is shown in the cumulative discharge data for the Middle River Rouge in Michigan, where the trend lines appear to increase at a more gentle of a slope. This is related to the negative correlation produced by linear regression when comparing population density and discharges.

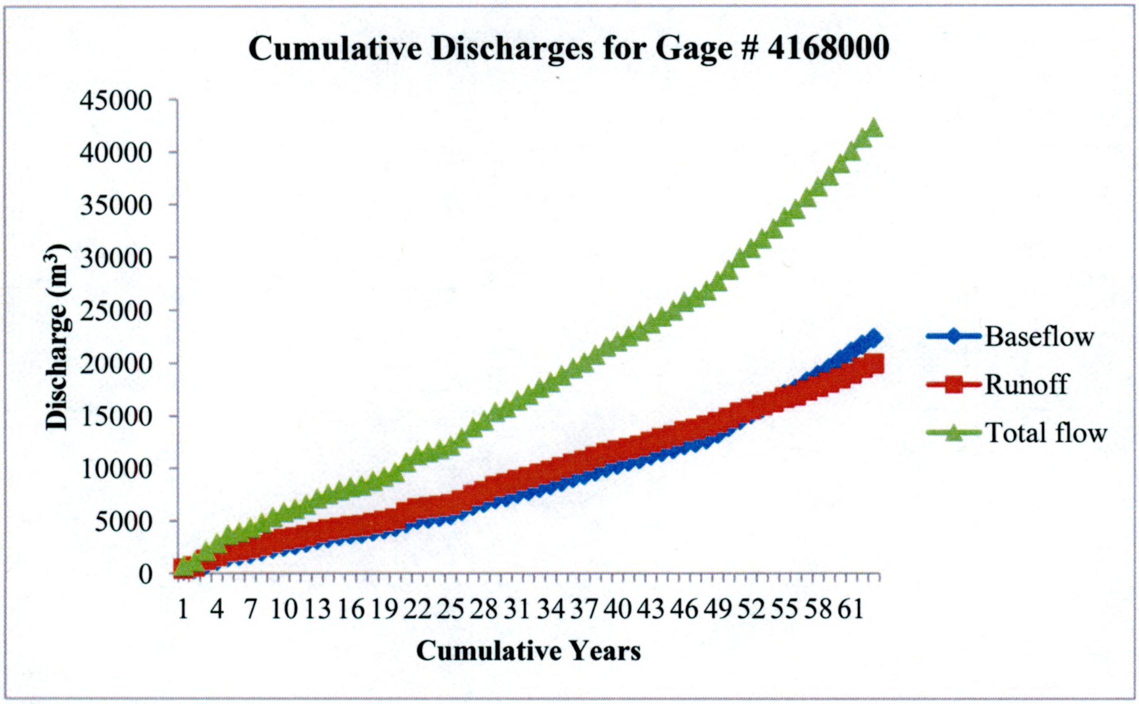

Figure 8. Cumulative Discharge 5. Gentle increases in the baseflow and runoff trend lines associated with the Lower River Rouge in Michigan are consistent with the negative trend produced by the linear regression of the data. The gentle slope is indicative of an indirect relationship between population density and discharges.

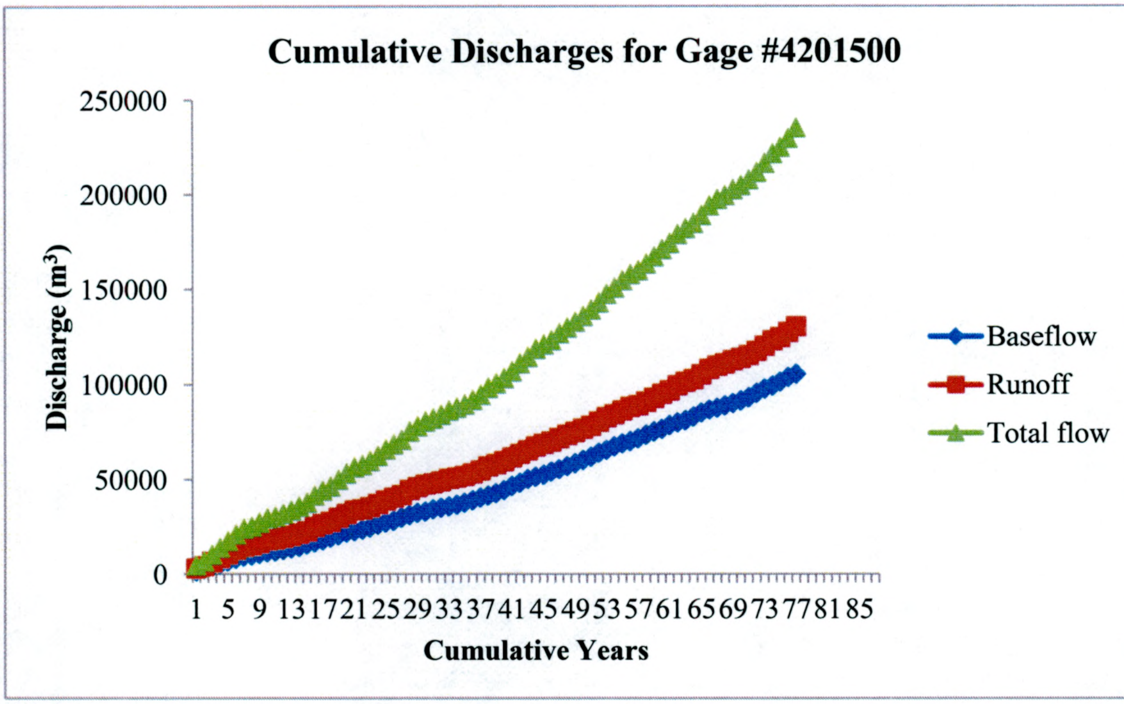

Figure 8. Cumulative Discharge 6. The steep increase of the discharges associated with the Rocky River in Ohio is representative of a positive trend in the linear regression. This image relates to the positive trend in that as population density changes, discharge changes in the same direction.

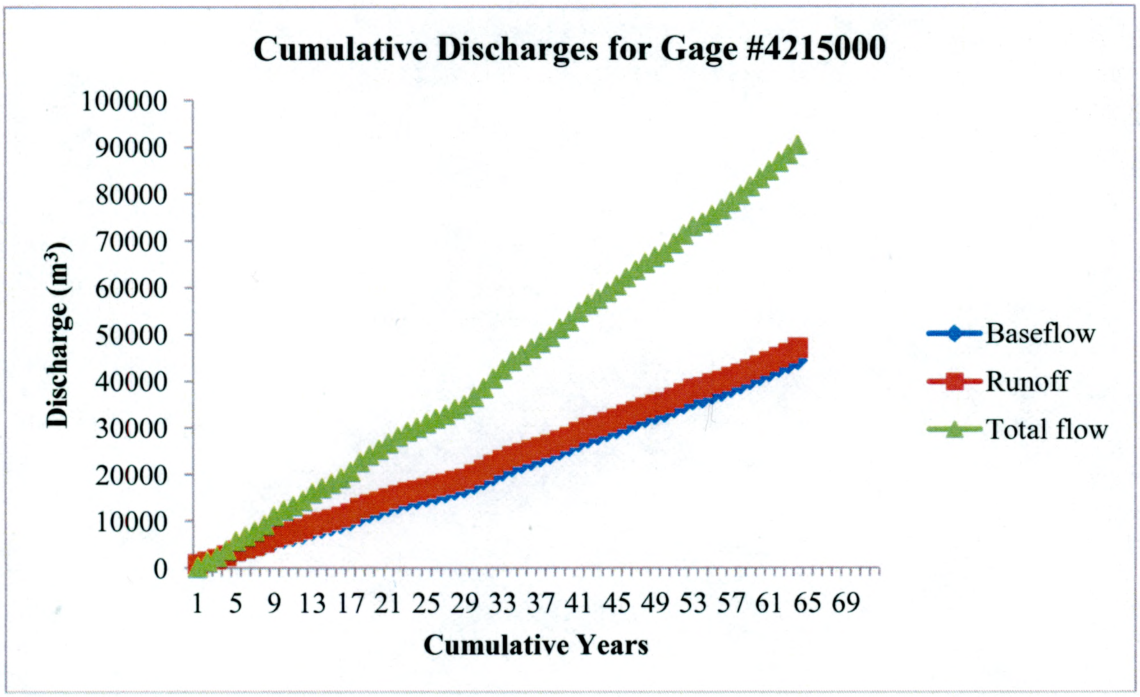

Figure 8. Cumulative Discharge 7. The dip in the trend line for the discharges associated with Cayuga Creek in New York, matches up with the time, in years, in which the population experienced a decrease. A steady trend upward from that point (~30 year) is consistent with the results produced in the linear regression for this gage in that there is a positive correlation between population density and discharges.

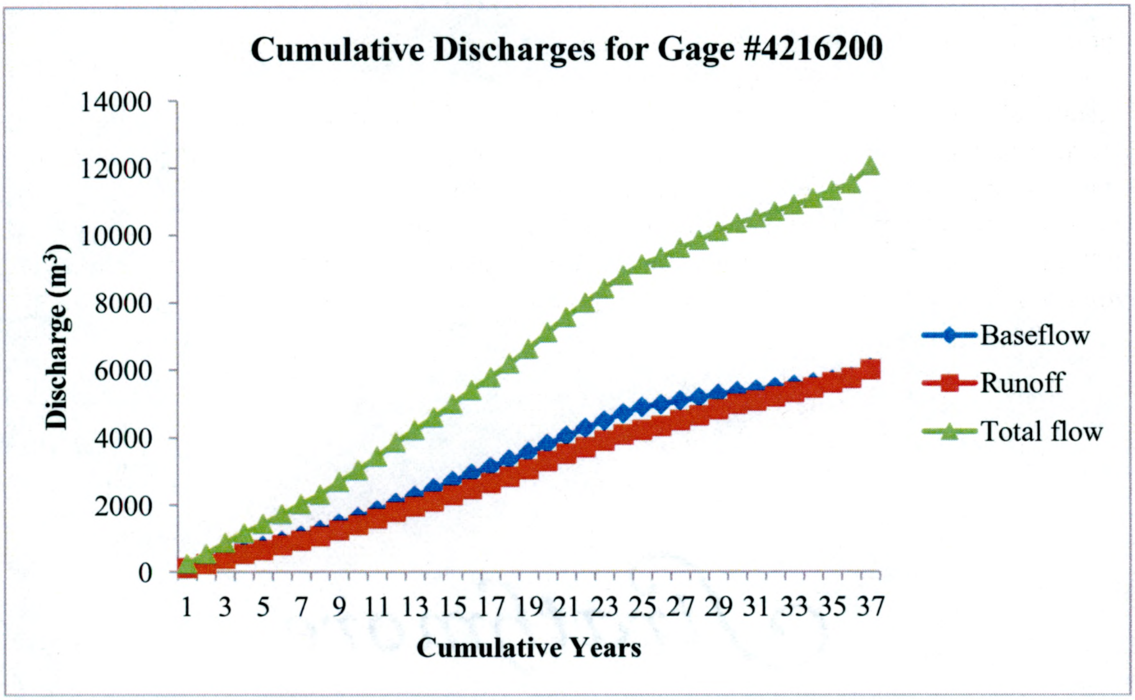

Figure 8. Cumulative Discharge 8. The cumulative discharge graph for Scajaquada Creek in New York is curious is that the change in slope steepness of the total flow line would intuitively represent a negative trend in the linear regression, however the Scajaquada Creek gages produced positively trending results. An explanation for these discharge trends, in relation to the positive correlation between population density and discharges, may be that this area experienced such a dramatic decrease in population so quickly that the water infrastructure system took a dramatic loss, in terms of total flow. Interestingly the change in slop on the cumulative discharge graph is consistent with the start of the flow decreases, including the lag, in the times series associated with the same gage (Time Series 8).

Tables.

Linear Data

Gage Name	Gage #	BF X-var	p-value	RO X-var	p-value	TF X-var	p-value
Little Pine Creek near Etna, PA	3049800	3.1E-10	0.770405937	-6.2E-10	0.63734532	-3.0E-10	0.89422727
Abers Creek near Murrysville, PA	3084000	4.4E-09	0.155192811	2.5E-09	0.419150303	6.9E-09	0.22905728
Turtle Creek at Trafford, PA	3084500	-2.1E-08	0.163232832	-3.6E-08	0.045296638	-5.7E-08	0.072889085
Chartiers Creek at Carnegie, PA	3085500	1.2E-10	0.948011007	-5.8E-10	0.174007203	-4.6E-10	0.839024593
Mill Creek at Youngstown, OH	3098500	-5.6E-07	0.481372561	-1.3E-07	0.500106767	-6.9E-07	0.484828885
Tinkers Creek at Bedford, OH	4207200	-1.8E-08	0.047289617	-1.0E-08	0.296576039	-2.8E-08	0.107679809
Mill Creek at Carthage, OH	3259000	2.5E-08	0.767546715	1.0E-08	0.58630699	3.5E-08	0.732592748
Wolf Creek at Dayton, OH	3271000	2.1E-07	**0.002359524**	5.6E-08	**0.000755748**	2.7E-07	**0.001702177**
Kearsley Creek near Davison, MI	4148140	-1.0E-09	0.946066889	7.1E-10	0.938765623	-3.3E-10	0.989136271
Paint Creek at Rochester, MI	4161540	2.0E-10	0.747137731	-1.6E-10	0.480161555	4.5E-11	0.95636218
Big Beaver Creek near Warren, MI	4162900	-1.1E-08	0.033617345	-1.0E-08	0.043128655	-2.1E-08	0.0320375
Plum Brook at Utica, MI	4163400	5.0E-07	0.248306563	1.4E-07	0.196954469	6.4E-07	0.236421125
N. Branch Clinton River near Mt. Clemens, MI	4164500	8.9E-10	0.048795545	4.8E-10	0.279950221	1.4E-09	0.117720371
River Rouge at Birmingham, MI	4166000	3.9E-09	**9.51344E-07**	1.9E-09	**8.81822E-06**	5.7E-09	**1.0782E-06**
Evans Ditch at Southfield, MI	4166200	1.7E-09	0.062478996	3.1E-09	0.03311686	4.7E-09	0.032574654
Upper River Rouge at Farmington, MI	4166300	7.1E-09	**7.55313E-10**	5.1E-09	**6.46974E-09**	1.2E-08	**4.72466E-10**
Middle River Rouge near Garden City, MI	4167000	-5.6E-08	**0.013387516**	-1.4E-08	**0.01016172**	-7.0E-08	**0.012654027**
Lower River Rouge at Inkster, MI	4168000	-4.1E-09	**5.48945E-13**	-1.2E-09	**0.002060523**	-5.3E-09	**1.37343E-09**
Ottawa River at University of Toledo at Toledo, OH	4177000	-5.1E-07	0.5365409	-1.1E-07	0.561032346	-6.2E-07	0.540814339
Rocky River near Berea, OH	4201500	-1.1E-07	**0.000999169**	-2.2E-08	**0.000652153**	-1.3E-07	**0.00076893**
Cayuga Creek near Lancaster, NY	4215000	1.1E-06	**0.000699094**	2.4E-07	**0.001653268**	1.4E-06	**0.000804712**
Cazenovia Creek at Ebenezer, NY	4215500	9.8E-10	0.630669079	-2.3E-09	0.406135042	-1.3E-09	0.770136763
Scajaquada Creek at Buffalo, NY	4216200	5.9E-08	**2.22674E-06**	1.5E-08	0.037022839	7.4E-08	**6.88741E-05**
Ellicott Creek below Williamsville, NY	4218518	-1.1E-07	**1.1957E-05**	-1.2E-08	0.632930457	-1.2E-07	**0.008891882**
Allen Creek near Rochester, NY	4232050	-1.8E-09	0.688097515	8.2E-09	0.015623589	6.4E-09	0.35969652
Irondequoit Cr. above Blossom Rd. near Rochester, NY	423205010	1.9E-08	0.320797981	1.4E-08	0.266284147	3.3E-08	0.272271438

Appalachian Plateaus	**Positive Trend**	**0.01 significance**
Central Lowland	**Negative Trend**	**0.05 significance**

Table 1. A table showing the statistically significant gages produced by linear regression. All of the gages with a 99% confidence are found within the Central Lowlands.

Linear Data

Gage Name	Gage #	POP INCREASE BF X-var	p-value	RO X-var	p-value	TF X-var	p-value
Little Pine Creek near Etna, PA	3049800	1.2E-09	0.282350372	8.8E-10	0.526758307	2.1E-09	0.375864797
Abers Creek near Murrysville, PA	3084000	-9.9E-09	0.558673791	-1.4E-08	0.422172038	-2.4E-08	0.460579904
Turtle Creek at Trafford, PA	3084500	-2.1E-08	0.163232832	-3.6E-08	0.045296638	-5.7E-08	0.072889085
Chartiers Creek at Carnegie, PA	3085500	1.6E-09	0.60219703	-3.2E-10	0.629978111	1.2E-09	0.733902566
Mill Creek at Youngstown, OH	3098500	1.2E-08	0.092755184	-1.5E-09	0.893586843	1.4E-08	0.422320473
Tinkers Creek at Bedford, OH	4207200	1.3E-07	0.061290724	1.3E-07	0.209057237	2.6E-07	0.110478816
Mill Creek at Carthage, OH	3259000	-2.5E-10	0.936186357	2.7E-10	0.945223604	2.5E-11	0.997061185
Wolf Creek at Dayton, OH	3271000	4.6E-07	**1.04146E-09**	1.1E-07	**2.56384E-09**	5.7E-07	**1.22391E-09**
Kearsley Creek near Davison, MI	4148140	8.3E-09	0.680558247	5.7E-09	0.631287208	1.4E-08	0.655861328
Paint Creek at Rochester, MI	4161540	2.0E-10	0.747137731	-1.6E-10	0.480161555	4.5E-11	0.95636218
Big Beaver Creek near Warren, MI	4162900	-1.1E-08	0.033617345	-1.0E-08	0.043128655	-2.1E-08	0.0320375
Plum Brook at Utica, MI	4163400	5.0E-07	0.248306563	1.4E-07	0.196954469	6.4E-07	0.236421125
N. Branch Clinton River near Mt. Clemens, MI	4164500	8.9E-10	0.048795545	4.8E-10	0.279950221	1.4E-09	0.117720371
River Rouge at Birmingham, MI	4166000	3.9E-09	**9.51344E-07**	1.9E-09	**8.81822E-06**	5.7E-09	**1.0782E-06**
Evans Ditch at Southfield, MI	4166200	1.7E-09	0.062478996	3.1E-09	**0.03311686**	4.7E-09	0.032574654
Upper River Rouge at Farmington, MI	4166300	7.1E-09	**7.55313E-10**	5.1E-09	**6.46974E-09**	1.2E-08	**4.72466E-10**
Middle River Rouge near Garden City, MI	4167000	-1.6E-07	**1.22831E-07**	-3.9E-08	**1.59652E-07**	-2.0E-07	**1.27432E-07**
Lower River Rouge at Inkster, MI	4168000	-1.7E-09	0.17111728	-4.1E-09	0.051098796	-5.8E-09	0.077107425
Ottawa River at University of Toledo at Toledo, OH	4177000	2.4E-06	**0.000274126**	5.5E-07	**0.000480999**	3.0E-06	**0.000303127**
Rocky River near Berea, OH	4201500	-1.1E-07	0.034482641	-2.6E-08	**0.010606009**	-1.4E-07	0.027226827
Cayuga Creek near Lancaster, NY	4215000	7.3E-07	0.04748823	1.5E-07	0.094221095	8.7E-07	0.054053423
Cazenovia Creek at Ebenezer, NY	4215500	1.3E-09	0.573312198	-1.5E-09	0.574241161	-2.5E-10	0.95849623
Scajaquada Creek at Buffalo, NY	4216200	5.1E-08	**7.55255E-05**	5.7E-08	**0.006048903**	1.1E-07	**0.000676285**
Ellicott Creek below Williamsville, NY	4218518				POP DECREASE ONLY ->		
Allen Creek near Rochester, NY	4232050	2.8E-08	**0.000820315**	1.2E-08	**0.007979485**	4.0E-08	**0.001236911**
Irondequoit Cr. above Blossom Rd. near Rochester, NY	423205010	1.9E-08	0.320797981	1.4E-08	0.266284147	3.3E-08	0.272271438

Appalachian Plateaus	**Positive Trend**	**0.01 significance**
Central Lowland	**Negative Trend**	**0.05 significance**

Table 2. A table showing the statistically significant gages produced when a linear regression was run comparing only population density increase against the discharge metrics.

Linear Data

Gage Name	Gage #	POP DECREASE BF X-var	p-value	RO X-var	p-value	TF X-var	p-value
Little Pine Creek near Etna, PA	3049800	-2E-08	0.340428059	-3E-08	0.332594565	-5E-08	0.325427287
Abers Creek near Murrysville, PA	3084000	4E-09	0.13553497	3E-09	0.311885317	7E-09	0.16964385
Turtle Creek at Trafford, PA	3084500	<- POP INCREASE ONLY					
Chartiers Creek at Carnegie, PA	3085500	-2E-10	0.686903887	-3E-10	0.226517214	-5E-10	0.440855699
Mill Creek at Youngstown, OH	3098500	-2E-06	0.028742539	-3E-07	0.045569874	-1E-06	0.133823706
Tinkers Creek at Bedford, OH	4207200	6E-09	0.641324043	3E-09	0.816819	9E-09	0.688804942
Mill Creek at Carthage, OH	3259000	-1E-08	0.668862394	-2E-08	0.671185177	-4E-08	0.666890427
Wolf Creek at Dayton, OH	3271000	2E-06	**8.18375E-07**	4E-07	**0.000284619**	2E-06	**1.86669E-06**
Kearsley Creek near Davison, MI	4148140	-9E-07	0.263195324	-5E-07	0.320114084	-1E-06	0.267103261
Paint Creek at Rochester, MI	4161540	<- POP INCREASE ONLY					
Big Beaver Creek near Warren, MI	4162900	<- POP INCREASE ONLY					
Plum Brook at Utica, MI	4163400	<- POP INCREASE ONLY					
N. Branch Clinton River near Mt. Clemens, MI	4164500	<- POP INCREASE ONLY					
River Rouge at Birmingham, MI	4166000	<- POP INCREASE ONLY					
Evans Ditch at Southfield, MI	4166200	<- POP INCREASE ONLY					
Upper River Rouge at Farmington, MI	4166300	<- POP INCREASE ONLY					
Middle River Rouge near Garden City, MI	4167000	5E-08	0.10744276	1E-08	0.13527672	6E-08	0.112354577
Lower River Rouge at Inkster, MI	4168000	-5E-09	**3.30124E-07**	-1E-09	0.019370883	-6E-09	**8.63851E-06**
Ottawa River at University of Toledo at Toledo, OH	4177000	9E-06	**2.41023E-06**	2E-06	**2.65465E-06**	1E-05	**2.40157E-06**
Rocky River near Berea, OH	4201500	-2E-09	0.707154791	-7E-09	0.250709356	-9E-09	0.396281549
Cayuga Creek near Lancaster, NY	4215000	5E-06	**3.89293E-08**	1E-06	**5.50024E-08**	7E-06	**3.96998E-08**
Cazenovia Creek at Ebenezer, NY	4215500	-2E-09	0.608009443	-7E-09	0.226119575	-9E-09	0.303853134
Scajaquada Creek at Buffalo, NY	4216200	7E-08	**0.000335298**	2E-08	0.124390978	8E-08	**0.002791471**
Ellicott Creek below Williamsville, NY	4218518	-1E-07	**1.1957E-05**	-1E-08	0.632930457	-1E-07	**0.008891882**
Allen Creek near Rochester, NY	4232050	2E-08	0.845071512	3E-08	0.689873143	5E-08	0.762184228
Irondequoit Cr. above Blossom Rd. near Rochester, NY	423205010	<- POP INCREASE ONLY					

Appalachian Plateaus	**Positive Trend**	**0.01 significance**
Central Lowland	**Negative Trend**	**0.05 significance**

Table 3. A table showing the statistically significant gages produced when a linear regression was run comparing only population density decrease against the discharge metrics.

LOG Data

Gage Name	Gage #	BF X-var	p-value	RO X-var	p-value	TF X-var	p-value
Little Pine Creek near Etna, PA	3049800	0.2	0.643257922	0.0	0.927760993	0.1	0.889730881
Abers Creek near Murrysville, PA	3084000	0.6	0.176393986	0.4	0.361263501	0.5	0.222733363
Turtle Creek at Trafford, PA	3084500	-0.9	0.193384719	-1.7	0.063136787	-1.3	0.078252139
Chartiers Creek at Carnegie, PA	3085500	-0.1	0.841827498	-0.5	0.032827621	-0.2	0.441273993
Mill Creek at Youngstown, OH	3098500	-1.5	0.71968476	-1.4	0.6024937	-1.6	0.661382187
Tinkers Creek at Bedford, OH	4207200	-0.9	0.031646894	-0.5	0.271409155	-0.7	0.080919754
Mill Creek at Carthage, OH	3259000	1.8	0.297274063	1.3	0.197906612	1.5	0.279303436
Wolf Creek at Dayton, OH	3271000	4.3	**6.14568E-05**	3.1	**1.9839E-05**	3.9	**4.35295E-05**
Kearsley Creek near Davison, MI	4148140	0.0	0.996544672	0.2	0.82092308	0.1	0.92628168
Paint Creek at Rochester, MI	4161540	0.5	0.037586928	0.4	0.049125091	0.5	0.035363258
Big Beaver Creek near Warren, MI	4162900	-3.1	**0.001820606**	-2.0	**0.013020099**	-2.4	**0.005271217**
Plum Brook at Utica, MI	4163400	2.8	0.036313976	2.3	0.036283081	2.6	0.038591831
N. Branch Clinton River near Mt. Clemens, MI	4164500	0.2	0.117787498	0.1	0.425709706	0.1	0.230124101
River Rouge at Birmingham, MI	4166000	0.7	**2.64695E-05**	0.7	**3.37068E-05**	0.7	**2.0715E-05**
Evans Ditch at Southfield, MI	4166200	0.5	**0.007043811**	0.8	**0.002337173**	0.7	**0.002482704**
Upper River Rouge at Farmington, MI	4166300	1.4	**9.62108E-10**	1.5	**4.8414E-09**	1.4	**7.55781E-10**
Middle River Rouge near Garden City, MI	4167000	-4.0	**0.006258648**	-3.2	**0.003870154**	-3.7	**0.005653588**
Lower River Rouge at Inkster, MI	4168000	-2.9	**8.87879E-13**	-1.2	**0.00051004**	-2.1	**4.46341E-09**
Ottawa River at University of Toledo at Toledo, OH	4177000	-1.9	0.563864643	-0.8	0.681552314	-1.5	0.592615639
Rocky River near Berea, OH	4201500	-1.0	**0.007858974**	-0.6	**0.003509393**	-0.9	**0.002519883**
Cayuga Creek near Lancaster, NY	4215000	4.0	**0.001067166**	1.8	**0.010847902**	3.2	**0.002331941**
Cazenovia Creek at Ebenezer, NY	4215500	0.1	0.557280059	-0.2	0.529096623	0.0	0.913566392
Scajaquada Creek at Buffalo, NY	4216200	7.2	**1.71084E-07**	1.6	**0.013235566**	4.1	**5.03429E-06**
Ellicott Creek below Williamsville, NY	4218518	-2.2	**6.79407E-06**	-0.3	0.644188899	-1.4	**0.008505673**
Allen Creek near Rochester, NY	4232050	-0.1	0.896840739	1.9	**0.00790679**	0.8	0.234080624
Irondequoit Cr. above Blossom Rd. near Rochester, NY	423205010	1.4	0.306640892	2.0	0.28511338	1.6	0.268716731

Appalachian Plateaus	**Positive Trend**	**0.01 significance**
Central Lowland	**Negative Trend**	**0.05 significance**

Table 4. A table showing the statistically significant data produced by the logarithmic regression of the data comparing population density against the discharge metrics.

LOG Data	LOG POP INCREASE					
Gage Name	BF X-var	p-value	RO X-var	p-value	TF X-var	p-value
Little Pine Creek near Etna, PA	0.43	0.315420878	0.55	0.368202482	0.46	0.336430521
Abers Creek near Murrysville, PA	-1.20	0.619077027	-1.83	0.515751403	-1.50	0.540987258
Turtle Creek at Trafford, PA	-0.91	0.193384719	-1.74	0.063136787	-1.31	0.078252139
Chartiers Creek at Carnegie, PA	0.16	0.714303016	-0.34	0.293982055	-0.01	0.981305195
Mill Creek at Youngstown, OH	1.06	0.057685451	0.04	0.95485675	0.53	0.387009834
Tinkers Creek at Bedford, OH	8.02	0.053464134	7.52	0.184345081	7.82	0.08827975
Mill Creek at Carthage, OH	0.16	0.835284465	0.29	0.741001484	0.23	0.771285141
Wolf Creek at Dayton, OH	7.80	**2.55426E-11**	5.21	**5.60289E-11**	6.91	**2.70405E-11**
Kearsley Creek near Davison, MI	0.38	0.701591015	0.64	0.554019751	0.48	0.632677722
Paint Creek at Rochester, MI	0.47	0.037586928	0.44	0.049125091	0.46	0.035363258
Big Beaver Creek near Warren, MI	-3.06	**0.001820606**	-1.99	**0.013020099**	-2.40	**0.005271217**
Plum Brook at Utica, MI	2.80	0.036313976	2.30	0.036283081	2.59	0.038591831
N. Branch Clinton River near Mt. Clemens, MI	0.17	0.117787498	0.10	0.425709706	0.14	0.230124101
River Rouge at Birmingham, MI	0.74	**2.64695E-05**	0.66	**3.37068E-05**	0.71	**2.0715E-05**
Evans Ditch at Southfield, MI	0.54	**0.007043811**	0.78	**0.002337173**	0.67	**0.002482704**
Upper River Rouge at Farmington, MI	1.35	**9.62108E-10**	1.53	**4.8414E-09**	1.42	**7.55781E-10**
Middle River Rouge near Garden City, MI	-10.07	**5.58855E-07**	-7.45	**1.71092E-06**	-9.28	**7.54438E-07**
Lower River Rouge at Inkster, MI	-1.98	0.234573518	-3.90	0.07692549	-3.01	0.116891
Ottawa River at University of Toledo at Toledo, OH	9.42	**0.000394022**	5.83	**0.000347582**	8.21	**0.00036541**
Rocky River near Berea, OH	-1.30	0.042775652	-0.78	**0.010178689**	-1.16	0.02127843
Cayuga Creek near Lancaster, NY	2.21	0.099370007	0.81	0.32035125	1.66	0.1486017
Cazenovia Creek at Ebenezer, NY	0.14	0.547859255	-0.13	0.633073706	0.01	0.978729016
Scajaquada Creek at Buffalo, NY	4.23	**6.29315E-05**	5.95	**0.004232695**	4.98	**0.000495807**
Ellicott Creek below Williamsville, NY			LOG Pop Den DECREASE ONLY ->			
Allen Creek near Rochester, NY	4.42	**0.000662348**	3.12	**0.005805582**	3.93	**0.000908723**
Irondequoit Cr. above Blossom Rd. near Rochester, NY	1.36	0.306640892	2.03	0.28511338	1.58	0.268716731

Appalachian Plateaus	**Positive Trend**	**0.01 significance**
Central Lowland	**Negative Trend**	**0.05 significance**

Table 5. A table showing the statistically significant gages produced when a logarithmic regression was run comparing only population density increase against the discharge metrics.

LOG Data		LOG POP DECREASE					
Gage Name	**Gage #**	**BF X-var**	**p-value**	**RO X-var**	**p-value**	**TF X-var**	**p-value**
Little Pine Creek near Etna, PA	3049800	-8.2	0.2219698	-11.0	0.2077066	-9.6	0.2043335
Abers Creek near Murrysville, PA	3084000	0.6	0.1589605	0.5	0.272237	0.6	0.1734397
Turtle Creek at Trafford, PA	3084500	<- LOG Pop Den INCREASE ONLY					
Chartiers Creek at Carnegie, PA	3085500	-0.1	0.771117	-0.4	0.2639061	-0.2	0.5081834
Mill Creek at Youngstown, OH	3098500	-7.2	0.0266208	-4.5	0.0315334	-6.3	0.0272451
Tinkers Creek at Bedford, OH	4207200	0.2	0.6686753	0.1	0.8620569	0.2	0.7421089
Mill Creek at Carthage, OH	3259000	-2.0	0.759203	-1.7	0.810631	-1.8	0.7872624
Wolf Creek at Dayton, OH	3271000	36.9	**1.275E-05**	20.9	**0.0003835**	31.3	**3.103E-05**
Kearsley Creek near Davison, MI	4148140	-58.9	0.2451176	-47.3	0.3548481	-54.4	0.268698
Paint Creek at Rochester, MI	4161540	<- LOG Pop Den INCREASE ONLY					
Big Beaver Creek near Warren, MI	4162900	<- LOG Pop Den INCREASE ONLY					
Plum Brook at Utica, MI	4163400	<- LOG Pop Den INCREASE ONLY					
N. Branch Clinton River near Mt. Clemens, MI	4164500	<- LOG Pop Den INCREASE ONLY					
River Rouge at Birmingham, MI	4166000	<- LOG Pop Den INCREASE ONLY					
Evans Ditch at Southfield, MI	4166200	<- LOG Pop Den INCREASE ONLY					
Upper River Rouge at Farmington, MI	4166300	<- LOG Pop Den INCREASE ONLY					
Middle River Rouge near Garden City, MI	4167000	2.4	0.2054655	1.3	0.3724105	2.0	0.244725
Lower River Rouge at Inkster, MI	4168000	-3.0	**1.095E-07**	-1.2	**0.0043689**	-2.2	**3.273E-06**
Ottawa River at University of Toledo at Toledo, OH	4177000	42.3	**1.293E-06**	23.4	**5.72E-06**	35.6	**2.039E-06**
Rocky River near Berea, OH	4201500	-0.1	0.61184	-0.3	0.2750986	-0.2	0.3840614
Cayuga Creek near Lancaster, NY	4215000	20.4	**3.731E-08**	10.9	**2.245E-07**	17.1	**5.102E-08**
Cazenovia Creek at Ebenezer, NY	4215500	-0.2	0.5794809	-0.6	0.2956088	-0.4	0.3437876
Scajaquada Creek at Buffalo, NY	4216200	8.1	**8.126E-05**	1.7	**0.0500349**	4.6	**0.0005869**
Ellicott Creek below Williamsville, NY	4218518	-2.2	**6.794E-06**	-0.3	0.6441889	-1.4	**0.0085057**
Allen Creek near Rochester, NY	4232050	5.1	0.7149829	6.1	0.6643785	5.5	0.6643517
Irondequoit Cr. above Blossom Rd. near Rochester, NY	423205010	<- LOG Pop Den INCREASE ONLY					

Appalachian Plateaus	**Positive Trend**	**0.01 significance**
Central Lowland	**Negative Trend**	**0.05 significance**

Table 6. A table showing the statistically significant gages produced when a logarithmic regression was run comparing only population density decrease against the discharge metrics.